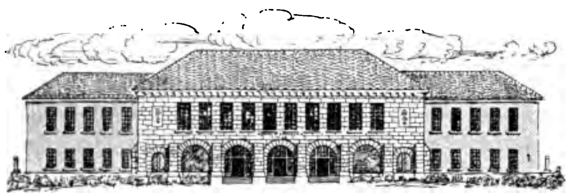

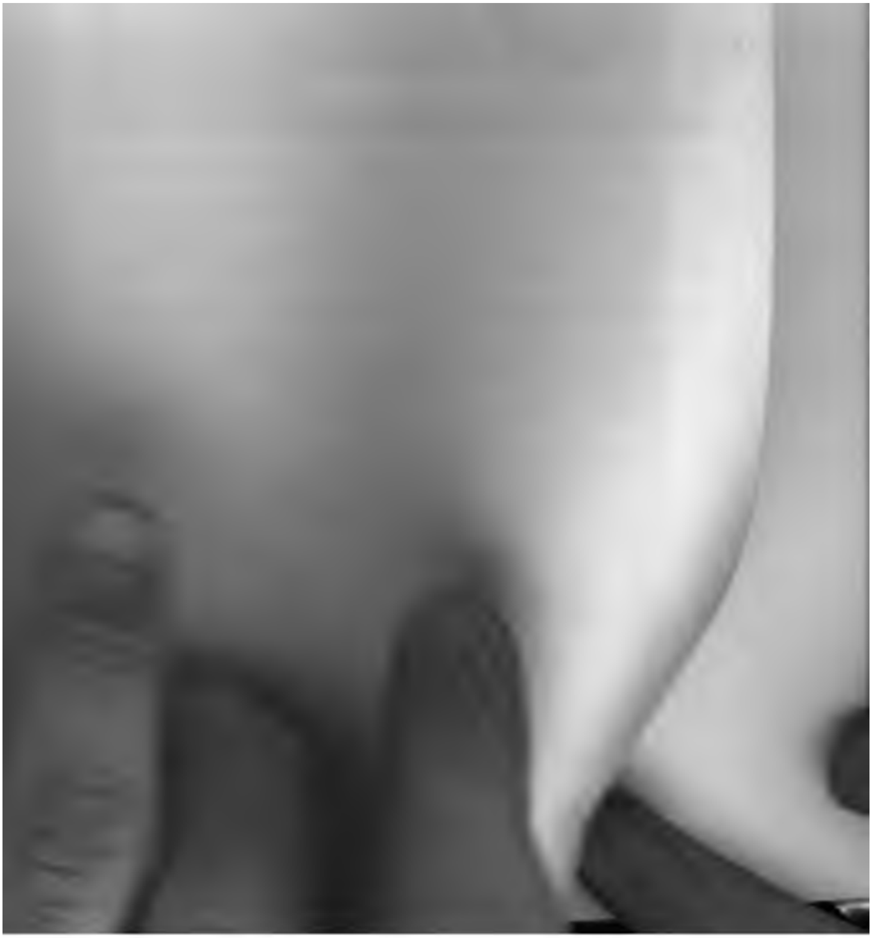

# PHYSIOLOGY OF MAN AND OTHER ANIMALS

BY

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TO

THE CLASS I MOST

ENJOYED TEACHING

body seemed beyond their grasp. They had no difficulty in understanding that the ameba gets oxygen because a gas passes in a definite direction, for the ameba was unfamiliar and a new idea could be easily and quickly gained concerning it; but almost simultaneously they would assert that a human being gets oxygen, even in a vitiated atmosphere, because his system needs oxygen. Their minds stopped working logically as soon as human physiology, the familiar thing, was in question.

Until the simple fact that natural laws act upon all organisms alike is grasped there can be no intelligent comprehension of physiology and no intelligent application of its laws to the health of the body. This fact is the keynote of its rational presentation, and it should be emphasized from the beginning, for if a correct general impression is established, it may serve as a basis upon which it is possible to build without first tearing down and re-establishing the foundation.

The course suggested in this book can be covered by the work of a year. It divides itself naturally into two parts. In the first part certain general principles are defined and are shown to govern the functions of organisms. In the second part modifications of these functions resulting from structural development are considered in representatives of the great groups of animals.

It frequently happens that a teacher must make her pupils conversant with a certain phase of a subject when she knows that it will be better for them to have some other phase of it emphasized. By following some such

plan as the one indicated she may stick to the letter of the law and at the same time follow the spirit of her better judgment, laying, in each individual case, the stress where it is most needed.

This book has been written with the conviction that the development of a pupil's mind is more important than the accumulation of facts and with the conviction that physiology may be made to contribute to this mental development by the appeal which it makes to the reasoning power. Children like to reason, and a sympathetic teacher, interested in the subject, and prepared to teach it, can, by appealing to the reasoning faculty, change the study of physiology from a perfunctory compliance with the law to a real pleasure.

The manuscript has been read by Miss A. St. L. Eberle, to whom I am much indebted for criticism and suggestion. I am further indebted to Messrs. Henry Holt and Company for much courteous consideration, and for permission to use illustrations from some of their publications; especially am I indebted for the use of those from "A General Biology" by Sedgwick and Wilson; "Principles of Physiology and Hygiene" by Dr. George Wells Fitz; "The Human Body" by H. Newell Martin; and "A Manual of Zoology" by Richard Hertwig.

# CONTENTS

## *PART I*

### INTRODUCTION

### CHAPTER I

#### LIVING MATTER

PAGE



### CHAPTER II

#### RESPIRATION

CHAPTER III

ASSIMILATION



CHAPTER IV

CIRCULATION



CHAPTER V

REPRODUCTION

CHAPTER IX

ECHINODERMATA



CHAPTER X

MOLLUSCA



CHAPTER XI

VERMES



CHAPTER XII

ARTHROPODA

## CHAPTER XIII

### VERTEBRATA



## CHAPTER XIV

### PLANTS

# INTRODUCTION

Physiology is a study of activity. It deals with the activity by which a living plant or animal manifests the fact that it is alive, and the activity of the various parts of its body which do the work required to keep it alive.

Physiology is related to anatomy in very much the same way that the work that a machine is capable of doing is related to its structure. When we study the anatomy of an animal we study the structure of its body, and we may do this through dissection after it has been killed. But when we study physiology we study the manifestation of life, the curious incomprehensible thing which marks the infinite, possibly the infinitesimal, difference between inert matter and a sensitive organism.

It has been customary to devote a large amount of space in text-books of human physiology to a consideration of anatomy. Structure and function have been presented together and causal relations have been established between them. This has led to confusion of thought. Structure has come to be regarded by young students as the underlying cause of function; and characteristics common to all animals as peculiar to human beings. This is fundamentally wrong. Structure can not initiate activity. It can only control or modify it. Although the activity of living organisms may be regu-

lated by their structure, it is dependent primarily on living matter itself. The functions of human beings are therefore not unique. They are but highly developed characteristics common to all animals.

We do not eat and breathe because we have a certain number of bones and a definite arrangement of muscles, though the manner of eating and breathing may be influenced by this arrangement. We might as well expect a steam engine to go because it has a certain number of wheels and pistons. These may determine the manner of its going, but without the steam it remains still. A dead man has the same gross anatomy as a living man. If anatomy were a determining cause of activity the functions of the body would not stop when death occurs.

Exactly what the difference between living and dead matter may be we do not know, but we do know the way in which living matter manifests the fact that it is alive; and we know that wherever it is found, in the simplest animal or in the most complex, these manifestations are the same. The point of departure in the study of physiology should therefore be the activity of the living substance. In studying this activity and the causes that control it we find that physiology is related to physics and chemistry and that this relation is more vital than its relation to anatomy. Through physics and chemistry we may explain the activity of living matter; through anatomy we explain nothing but accidental modifications of its activity.

The human body, though the most complex and wonderfully efficient machine in existence, has in common with the simplest animals and plants only the functions

that belong to living matter. Every organism assimilates food, substances circulate through all parts of its body, it breathes, it moves and it is able to produce its kind. These are the functions that we are to study. To explain their simple universal features we must have recourse to the principles of physics and chemistry. No adequate explanation can be made of any process without a knowledge of these principles, for in all purely physical operations the animal obeys certain natural laws, usually without knowledge on its part, of what it is doing and certainly without volition. But as the peculiar way in which the functions manifest themselves is dependent upon structure, to explain the manner of their occurrence in any particular animal we must have recourse to anatomy.

# PART I

# CHAPTER I

## LIVING MATTER

**Organisms Composed of Living Substance.**—Every organism is composed mainly of living substance. Its characteristics, functions and powers are dependent on the nature of the living substance. If then we are to understand the physiology of any plant or any animal we must know something about this substance. We must study it, not in its most highly developed form, as it appears, for instance, in the muscles and nerves of human beings, but in its simplest state. We shall then find out what the characteristics are that distinguish it from everything else. These characteristics are few and always the same. They may become more complex as the result of some special development, but no matter how highly developed this substance may be, it can not take on new powers, it can only develop and modify those that belong to it simply because it is alive.

**Appearance of Living Substance.**—If we scrape a few hairs from the stamen of such a flower as the wandering jew and examine them with a compound microscope we can see what this substance looks like. Each hair is made up of a series of compartments which appear more or less transparent (Fig. 1, A). Within the transparent space in each compartment a shadowy, granular

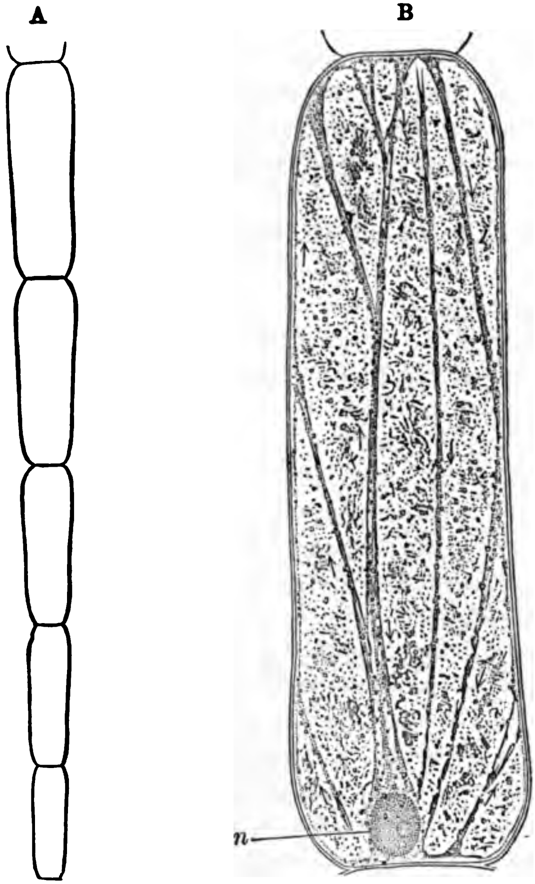



**Fig. 1.**—*A*, a hair from the stamens of spiderwort; *B*, a single cell enlarged. The circulation of the protoplasm is indicated by the arrows; *n*, nucleus. (From Sedgwick and Wilson.)

substance slowly streams about (Fig. 1, B). This granular substance is the living substance, or *protoplasm,* as it is usually called. The most remarkable thing that we notice about it, is that it moves apparently without

anything to make it move. The streams of protoplasm seem to flow from a spot of thickened protoplasm called the *nucleus.* This spot is always a center of activity. The transparent space around the protoplasm is called the *vacuole;* the enclosing wall, the *cell-wall;* and the entire structure, the *cell.*

**Meaning of the word Cell.**—The name cell was given to the structure when microscopes were very poor. Investigators saw only the walls and attached undue importance to them. The name now refers not to the walls but to the living substance which we know to be infinitely more important. A cell is a little mass of protoplasm which contains a nucleus. It may, or may not, be surrounded by a definite wall, and it may, or may not, contain other things.

**Importance of the Cell.**—A simple cell, or protoplasm in its simplest form, is the starting point of every plant and every animal. Some plants and animals never get beyond the starting point; that is, they remain all their lives in the one-celled stage. Such single cells are able to do everything necessary to the life of an independent organism. By studying these one-celled forms, then, it is possible to discover the wonderful powers that characterize living substance and all living organisms.

**Irritability.**—If a drop of stagnant water is placed on a glass slide and examined with a compound microscope, minute, one-celled, transparent animals may be seen moving swiftly across the field. If one of them is quiet long enough, we may see in its body what we have already seen in the hair cell. The protoplasm is moving. But as we look, the animal scurries away.

This independent movement from place to place is merely a mechanical response to some form of motion within the cell. On the surface of some of these animals are tiny, hair-like projections called cilia (Fig. 2). The protoplasm inside moves in such a way that the cilia wave to and fro; the animal then moves through the water like a boat propelled by oars. Still others have a tail-like projection which becomes fastened to something in the water (Fig. 3). Within the tail is a thread of protoplasm attached alternately first on one side and then on the other. This thread contracts and the animal is pulled away from anything that may happen to touch it. Movement in response to an outside stimulus, or irritation, is called *irritability*.

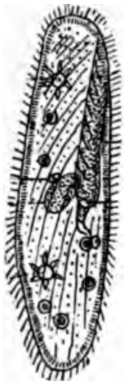


**Fig. 2. — Paramecium showing cilia. (From McMurrich.)**

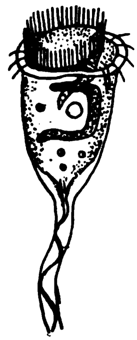


**Fig. 3.—Vorticella showing stalk of contractile protoplasm. (From McMurrich.)**

**Assimilation.**—Another thing that attracts the attention as we watch these animals in the drop of water, is that some are larger than others of the same kind, just as cats are larger than kittens, and men are larger than boys. We may infer from this difference in size that they have the power of growth, or the power to add new protoplasm to their bodies, and that in order to get the materials for the manufacture of protoplasm,

they must take in food. If we watch patiently we may see them eat. They do this in a primitive way. They simply engulf another organism smaller than themselves. The parts of this organism which are unfit for the building up of new protoplasm they eject from their bodies. The nutritious material they retain and manufacture into protoplasm. This process is called *assimilation.*

**Reproduction.**—If we continue to watch, we may notice that when one of these animals has attained its full growth it splits into two small ones. (Fig. 4).

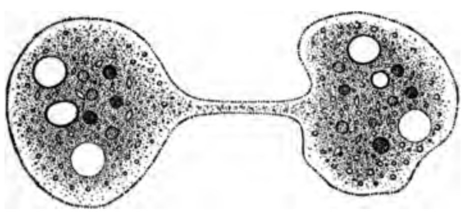


FIG. 4.—*Ameba* dividing by fission. (From Sedgwick and Wilson, after Leidy.)

Each of these assimilates food, grows to maturity and in turn divides. The number of animals is thus rapidly increased. This is the simplest form of *reproduction.*

**Universal Characteristics.**—Irritability, assimilation, and reproduction are universal characteristics of living matter and of all organisms composed of it. The study then of any organism means the study of the specific way in which these characteristics manifest themselves.

**Non-Living Matter in a Living Cell.**—Suppose we look at a cell which differs from those we have seen in

that it contains other substances besides the living substance. Such a cell may be obtained by cutting a very thin section of a potato. (Fig. 5). When we look at the section with the compound microscope we see two things; the walls of a series of irregular boxes, and enclosed by them a great many transparent globules.

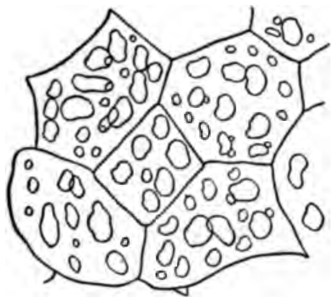


FIG. 5.—A section of potato showing starch grains within the cells.

**Starch in the Potato.**—What are these globules? Doubtless in the beginning chemists tried many tests before they found out, but now that we know the test to apply, it is a very simple matter to prove that the globules are made of starch. Iodine stains brown whatever it touches except starch and this it stains blue. We may test this by putting a few drops on a lump of starch and on something which we know contains no starch. If we put a drop of iodine on the potato cell the protoplasm and the cell walls turn brown and the globules turn blue. The globules are therefore made of starch. After this we will refer to them as starch grains.

**Starch Used for Food.**—What are the starch grains in the potato for? The starch is made and stored for the sake of furnishing the living substance of the potato with something with which it can repair wear and tear. It is one of the substances out of which new protoplasm is made.

**A Question Simplified.**—If we understand how the starch grains are made and how they get into the cells of the potato it will simplify the attempt to explain similar processes in the human body. Starch is manufactured inside the plant of water and carbon dioxide. The water enters the plant through its roots, the carbon dioxide through its leaves. How? We may consider the root and the leaf as more or less hollow structures covered with a thin, moist membrane. The membrane is a solid, the water is a liquid, and the carbon dioxide is a gas. How do a gas and a liquid pass through a solid? In order to explain this, we must know something about the nature of a gas, a liquid, and a solid.

**Matter.**—Every substance, everything in the world that can be called matter, is made of very tiny particles. These little particles are constantly rotating, or vibrating very rapidly, and they have more or less power to move away from each other.

If they move very slightly so that they do not change their relative positions, the substance has a definite shape and a definite volume and we call it a solid. If they move freely but not entirely away from each other the substance has a definite volume but no definite shape and we call it a liquid. If their motion is unrestricted so that they may fly entirely away from each other the substance has neither definite shape nor definite volume and we call it a gas.

**Heat.**—The word heat means rapidity of vibration. In response to heat a substance may change from a solid to a liquid, or from a liquid to a gas. As it grows hot its particles move more rapidly and push farther and

farther apart. They do not change in size or in number but the spaces between them become larger and the substance occupies more space than it did before. (Fig. 6).

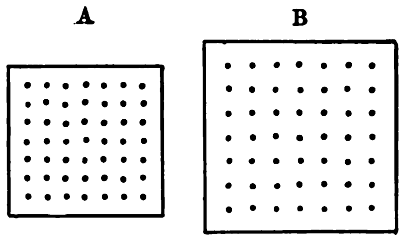



**Fig. 6.—A diagram illustrating expansion. A bit of matter, *A*, before; *B*, after the application of heat. The particles have not changed, but as they are farther apart they occupy more space.**

When butter melts, it expands until it becomes a liquid. When water evaporates, it expands until it becomes a gas. In both cases the increased motion of the particles represents an increase in heat, and the increase is the same whether the process takes place quickly or slowly. The increase of heat, or motion, on the part of one substance means a corresponding loss of heat, or motion, on the part of some other substance, thus there can be no evaporation unless something is cooled in the process. If a hot substance is brought in contact with a cold substance, the more rapidly moving particles transfer their motion to the more slowly moving ones as a bat does to a ball, and as the one substance grows warmer the other grows colder until the temperature of both is the same. If a substance evaporates from the surface of the body, it takes heat from the body in so doing and we feel cooler.

**Diffusion.**—Water apparently disappears when it

evaporates. Where does it go? As it becomes a gas, the particles on the surface move away from their fellows and pass into the nearest space that is open to receive them. If the water is in contact with air, this space is between the particles of the air. (Fig. 7, A). The air

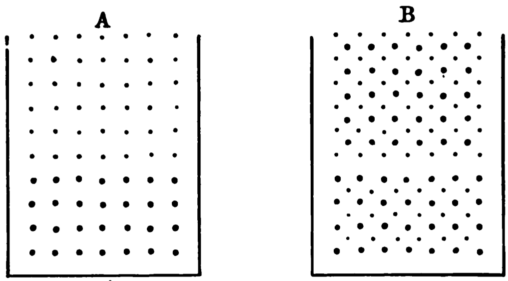



FIG. 7.—A diagram illustrating diffusion. Two substances in contact, *A*, before; *B*, after diffusion has begun.

particles are also moving rapidly and they pass into the spaces between the particles of the water. (Fig. 7, B). The particles of each substance then continue to move from space to space in the other until each holds as much of the other as it can, or until one of them is entirely taken up by the other. This process is called *diffusion.*

**Osmosis.**—If the water were separated from the air by a moist membrane, diffusion would take place through the membrane. As the membrane is a solid, its particles do not move away from each other, but through the spaces between them the particles of air and of water pass to the other side and the two substances become intermingled. (Fig. 8). This process is called *osmosis.*

**The Question Answered.**—Through the process of osmosis a liquid or a gas can pass through such a solid

as a moist membrane. A cell-wall is a moist membrane. If the particles of a liquid or a gas come in contact with it they pass into the spaces between the particles of the

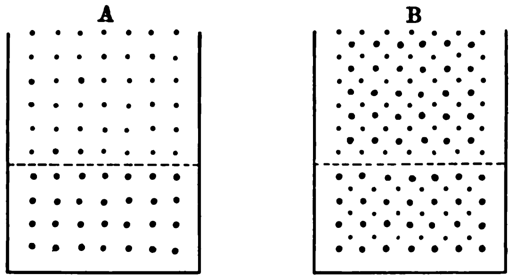



FIG. 8.—A diagram illustrating osmosis. Two substances separated by a membrane, *A*, before; *B*, after osmosis has begun.

cell-wall and get through to the other side. In this way water and carbon dioxide pass into the root and leaf, starch into the potato cell, and substances pass from cell to cell in the bodies of organisms.

**Chemical Action.**—How are starch grains made? Water and carbon dioxide enter the plant by a physical process which involves no change in their nature. In the plant they are manufactured into starch, an absolutely different substance. This is done by a chemical process. In chemical action two or more simple substances unite to form a complex substance, or a complex substance splits into the simple substances of which it is composed.

**Combustion.**—Carbon dioxide is a colorless gas, and as its name indicates it is made of two substances, carbon and oxygen. Oxygen is a colorless gas and as far as appearance goes it is not to be distinguished from carbon

dioxide. Carbon is a black solid best known in the form of charcoal.

When oxygen unites with a substance, the substance is said to burn. When wood burns oxygen from the air unites with two substances in the wood, carbon and hydrogen, a colorless gas. The union of oxygen with carbon produces carbon dioxide; with hydrogen, water. The substances in wood that do not unite with oxygen are left unburned in the form of ashes.

When a substance burns its weight is increased by the weight of the oxygen that unites with it. It may be hard to realize that an invisible gas has weight and that a thing weighs more after it is burned than before, but the fact is easily proved. When magnesium wire is burned, the resulting product is a white powder called magnesium oxide. The weight of the powder is greater than that of the original piece of wire by the amount of oxygen which has united with it.

**Characteristics of Hydrogen, Carbon Dioxide, Oxygen.**—If a burning splinter is thrust successively into three jars containing hydrogen, carbon dioxide and oxygen its behavior in the three cases is markedly different. In the jar of hydrogen, it goes out, but the hydrogen itself begins to burn at the mouth of the jar with a blue flame. The heat of the burning splinter raises the hydrogen to the kindling temperature and it unites with oxygen from the air. The water that is formed appears in drops on the side of the jar.

In the jar of oxygen the splinter burns for a moment much more freely than it does in the air; then it goes out. In the carbon dioxide, it instantly goes out.

If a small amount of clear lime water, which is a test for carbon dioxide, is now put into these two jars, it turns milky in both, showing that in the one case oxygen united with carbon from the splinter to form carbon dioxide, and that in the other the carbon dioxide was unchanged. Carbon dioxide does not burn because it can not hold any more oxygen; it does not allow anything to burn in it because it will not allow the oxygen which it holds to unite with anything else. It is therefore inactive.

Oxygen is very active. It burns, or unites with, almost everything with which it comes in contact if the temperature is raised to the kindling point. Even iron burns in it, forming iron oxide or rust.

**Heat and Chemical Action.**—There is a very close relation between heat and chemical action. We use a burning match to light the fire because heat is necessary to bring about chemical action, and we sit near the fire to get warm because chemical action gives rise to an increase in heat. Heat, then, becomes an evidence that a chemical action which may be invisible is taking place. Heat will be given off whether the action takes place quickly or slowly, but if the action takes place slowly, as in the rotting of wood, or in the rusting of iron, it is not evident to the senses.

**Manufacture of Starch.**—When starch is made, six parts of carbon dioxide and six parts of water unite chemically to form one part of starch. Twelve parts of oxygen are left over. ($6CO_2+6H_2O=C_6H_{12}O_6+12O$). The process takes place in the leaf in the presence of sunlight, through the activity of *chlorophyll*, the sub-

stance which gives plants their green color. If green water plants are placed in a jar of water in the sunlight, bubbles of gas may be seen passing away from them. If this gas is caught in a test tube and touched with a lighted splinter its behavior proves at once that it is oxygen. Its presence is a sign that the plant is rapidly making starch. (Fig. 9).

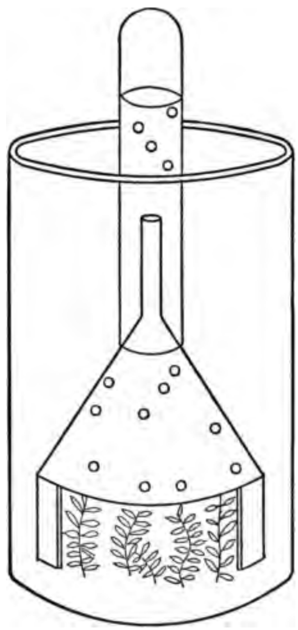


FIG. 9.—Alga giving off oxygen. (After Bailey.)

**Transfer of Starch.**—As starch is a solid that does not dissolve in water it cannot pass out of the leaf where it is made until it is changed to a soluble form. Through the activity of certain complex substances (see enzymes) which will be described later it becomes converted into sugar. In this form it passes into the sap, which carries it throughout the plant. When the sugar reaches the potato the complex substances reverse their action and turn the sugar into starch, in which form it is stored for future use. Though there is an obvious advantage to the plant in this transformation it takes place not for this reason but as a result of chemical activity.

**Purification of Air.**—The work that plants do in keeping alive is of inestimable benefit to man. In making

starch they not only provide him with a large proportion of his food, but by taking in carbon dioxide and giving off oxygen, they purify the air, so that it is fit for him to breathe.

**Air, its Composition and Pressure.**—Air is a physical mixture, not a chemical compound. When pure, it is composed largely of two gases, oxygen and nitrogen, with small traces of water vapor and carbon dioxide. Besides furnishing gases that living organisms need, it affects them in many other ways, chiefly through its weight, which is enormous. It presses upon all sides of us in every direction with a force of fifteen pounds for every square inch of surface. This force represents the weight of a column of air with a base of one square inch stretching from the earth to the limit of the atmosphere. One would think this weight enough to crush a delicate little organism, but the external pressure is so nicely adjusted to the pressure within the body that it does no harm, and it regulates many functions. In the hair cell the streams of protoplasm are separated by large, transparent spaces which seem empty. They are, however, filled with a transparent liquid which by pressing back upon the wall with a force of fifteen pounds to the square inch neutralizes the air pressure, which would otherwise crush out the spaces and prevent their existence. This liquid is sap, or water containing dissolved substances, one of which is sugar.

**Summary.**—Every organism has a definite cellular structure, that is, it is made up of one or more cells, or little masses of protoplasm, each of which contains a nucleus and is surrounded by a cell-wall. It is further

distinguished by physiological qualities dependent upon the peculiar characteristics of the protoplasm, or living substance of which it is composed.

This substance is distinguished from non-living substances by three qualities: irritability, or the power to move; assimilation, or the power to use food substances; and reproduction, or the power to form new protoplasm. These qualities of living matter are responsible for the behavior of organisms as independent beings.

Living matter responds to a stimulus with some form of motion. This motion may take the form of a circulation within the cell, or of a contraction. If the contractions are organized they will result mechanically in a movement of the whole, or of some part, of the independent organism from place to place. Food substances are used by independent organisms in such a way that new protoplasm is formed, endowed with the power of becoming differentiated into the specific tissues of a specific organism. Food that a sheep eats is never transformed into the muscles of a fish. Reproduction of independent organisms involves the formation of a cell endowed with the power to become a new individual like the parent.

These functions are controlled by physical and chemical laws. The most important of these are (1) All matter is composed of particles that move and have spaces between them. (2) This motion is the equivalent of heat which may be transferred without loss from particle to particle and from substance to substance.

As the particles move faster they move farther away from each other, and the substance occupies a larger

area than before. This expansion may continue until a solid becomes a liquid and a liquid becomes a gas. As a liquid evaporates its particles get into the spaces between the particles of other substances. If this diffusion takes place through a membrane, the process is called osmosis.

A physical change does not disturb the nature of a substance, but in a chemical change new substances are formed either by the union of simple into complex, or the disintegration of complex into simple substances. The oxidation of carbon and hydrogen in the burning of wood is similar to the oxidation of those substances in the human body; in both cases carbon dioxide and water are formed. The passage of water and carbon dioxide through a membrane is typical of the way in which most substances pass from cell to cell in the human body.

## CHAPTER II

## RESPIRATION

**A Universal Process.**—All living things breathe. A fish in the water and a horse on land breathe; an ameba, the simplest animal, and a human being, the most complex, breathe; a tree and a violet, a jelly fish and a mushroom, breathe. They do not take in air and give it off by means of a movement of the chest cavity, for that is a characteristic of human beings and certain other vertebrates, and is only an accident connected with the process, but nevertheless they breathe.

**The Process Defined.**—What do we mean by this word breathe? If we study these diverse cases and disregard accidental peculiarities and complications that result from structure, or from habit of life, we find that when an organism breathes two very simple things invariably occur; oxygen passes into its body, and carbon dioxide passes out of it. This double process is called breathing or respiration.

**Necessary Conditions.**—Oxygen and carbon dioxide are gases. Whenever an animal breathes then a gas passes into the body and a gas passes out. In order that this may occur two obvious conditions must be fulfilled; first, the gases must be present; second, some means of passage must exist. As the simplest animals have the entire

body surface covered with a moist membrane, gases can get into, or out of, the body only by passing through the membrane. This fact is important because, (1) All animals have more or less of the body surface covered with a moist membrane; (2) Any gas coming in contact with a moist membrane passes through.

**The Law of Gases.**—Why should a gas pass through a membrane? When we explain this we shall have explained the underlying principle which governs respiration. *A gas always passes in the direction of the least pressure.* It does this even if it has to pass through a membrane. If the pressure of a gas on the outside of a membrane is greater than the pressure of the same gas on the inside, then that gas must pass from without in; conversely, if the pressure is greater on the inside than on the outside, it must pass from within out. The pressure of carbon dioxide is continually greater on the inside of the body than on the outside; it must, therefore, pass out of the body. The pressure of oxygen is continually greater on the outside of the body than on the inside; it must therefore pass into the body.

**Passage of a Gas Through a Membrane.**—If a gas is in contact with a moist membrane, its particles, moving in every direction quite unrestrainedly, hit against the membrane. When they hit another particle they rebound, but when they come to a space they pass through if the space is large enough. The ease with which a substance passes through a membrane, or whether it passes through at all, depends on the relative size of its particles and of the spaces between the particles in the membrane. In a membrane the spaces between the particles

are larger than those in such a solid as glass or steel, but they are still so tiny that they are invisible and they must not be confused with holes. A membrane has no "holes" in it.

**Influence of Pressure on Rate of Passage.**—A gas will pass through a membrane slowly or quickly according to the number of particles that hit the membrane in any given interval of time, and this depends of course on the amount of gas that is present. The greater the amount of gas in a given space, the greater will be the number of particles that bombard the membrane in a unit of time, the number that reach spaces, and the number that pass through. This is but another way of

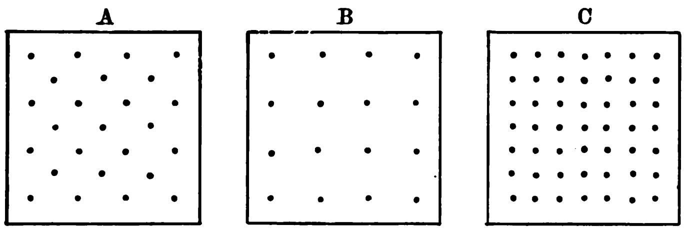



**Fig. 10.—A diagram illustrating the influence of pressure on the passage of gas.**

saying that the pressure of a gas determines the rapidity with which it passes through a membrane (Fig. 10).

**Establishment of an Equilibrium.**—Suppose (case 1) two empty spaces of equal size, A and B, should be separated by a membrane, and a gas should be introduced into A (Fig. 11). Immediately its particles would rush through the membrane and begin to fill space B. As soon as a particle arrives in B it stands a chance of again hitting the membrane and of getting

back to A. As long as the number of particles is greater in A than in B, a greater number from A than B hit the membrane in a unit of time, and the passage from A to B is more rapid than from B to A (Fig. 12). In course

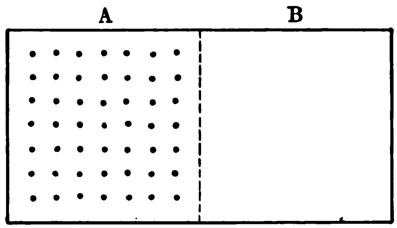



FIG. 11.—Case 1. A gas confined by a membrane.

of time the number of particles in B equals the number in A. The chance of hitting the membrane and of passing through is then the same in both spaces (Fig. 13). In other words, when the pressure of a gas is greater

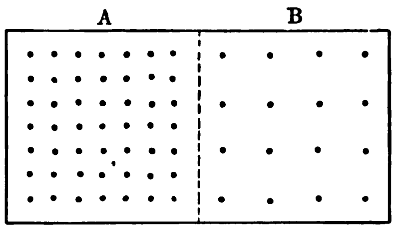



FIG. 12.—Case 1, after an interval.

on one side of a membrane than on the other, the passage takes place in both directions, but from the side of greater pressure it overbalances that from the side of less pressure until the pressure on the two sides is equal, when an equilibrium is established. Equilibrium does not mean that passage stops. It means that in any

given interval of time the number of particles that pass through from one side equals the number that pass through from the other.

**Independent Behavior of Gases.**—Suppose (case 2) two spaces of equal size, A and B, should be separated

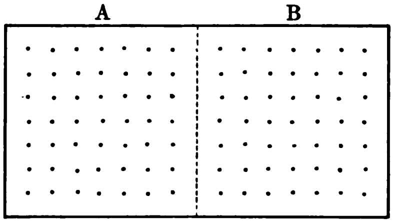


FIG. 13.—Case 1: Equilibrium.

by a membrane, and suppose a gas X should be introduced into A and a gas Y into B (Fig. 14). Each one of these gases would act independently of the other. It would act as if the other were not there, as in case 1, and

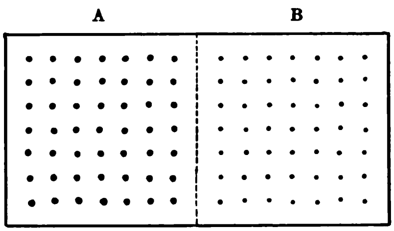


FIG. 14.—Case 2: Two gases separated by a membrane.

would establish its own equilibrium (Fig. 15). If the two gases should be kept from forming an equilibrium by some mechanism that would keep the pressure of X always greater in A than in B and the pressure of Y always greater in B than in A, the passage would simply

continue independently always in excess in the same direction for the same gas. If the pressure of X were very much greater in A than in B the passage from the side of less pressure might be so small that it could

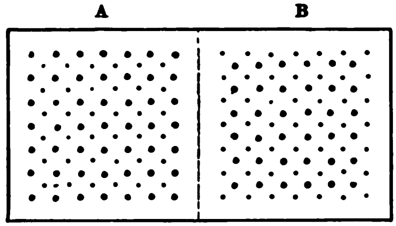



FIG. 15.—Case 2: Two gases in equilibrium.

be ignored in comparison with the passage from the other side; we would then speak of the passage as if it were in one direction only.

**Application to Respiration.**—Case 2 represents the condition in respiration (Fig. 14). Oxygen or X is on one side of the membrane and carbon dioxide or Y on the other side. Each gas passes through and establishes its own equilibrium quite independently of the other (Fig. 15). The pressure of oxygen is so much greater on the outside of the membrane than on the inside that we ignore the small amount that passes out, and speak only of the taking in of oxygen; and the pressure of carbon dioxide is so much greater on the inside than on the outside that we ignore the small amount that passes in and speak only of the giving off of carbon dioxide. No equilibrium can be established in either case, for in the tissues oxygen is continually being used and carbon dioxide is continually being formed.

**Free Oxygen.**—In breathing, animals use free oxygen as it exists in air; they do not take it from water or from any other compound containing oxygen. Animals that are habitually surrounded by water get their oxygen from air that has entered the water by the process of diffusion. The water brings the air in contact with the membrane, and oxygen enters and carbon dioxide passes off in the manner described above.

**Equilibrium of Nitrogen.**—Oxygen and carbon dioxide are the only gases in air that are concerned in respiration. Any gas that is in the air, however, may enter the body. Air is composed principally of oxygen and nitrogen. Nitrogen as well as oxygen passes through the membrane, but, as living organisms do not as a rule use free nitrogen, it establishes an equilibrium and does not concern itself with the activity of the body except under extraordinary conditions.

**Respiration in Specific Animals.**—In considering the respiration of any specific animal it is necessary (1) to locate the moist membrane, (2) to ascertain the means by which air is brought in contact with the membrane.

**Lower Animals.**—In one-celled animals the process is simple. It takes place at any point on the body's surface, for the animal is merely a mass of protoplasm surrounded by a membrane (Fig. 16). Oxygen is dissolved in the water in which the animal lives; as it comes in contact with the surface of the animal it enters because its pressure is greater in the water than in the body of the animal. The pressure of oxygen is always low in the animal because as soon as it gets inside it is carried to all parts of the cell and is used in the manu-

facture of new protoplasm. As carbon dioxide is formed in this process its pressure is always greater in the body of the animal than in the surrounding water. It therefore passes out of the animal.

In the next higher group of animals the tissues are still simple enough to allow the gases in the water that

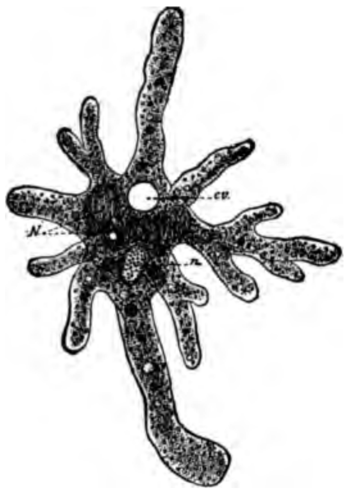



FIG. 16.—*Ameba.* (From Hertwig, after Leidy.) *cv*, contractile vacuole; *n*, nucleus; *N*, food-vacuoles.

bathes them to pass through. Their manner of breathing therefore does not differ from that of one-celled forms.

**Higher Animals.**—As animals become more highly developed the number of cells in the body increases, division of labor occurs and similar cells become grouped into tissues, each with its own special work. As the whole body is then no longer adapted to the absorption

of oxygen, a special membrane is set apart for this function. This means (1) that the oxygen comes into the body at a definite point, (2) that this oxygen must be transferred from this point to every cell in the body. The blood is the carrier. It comes to the tissues laden with oxygen. In the tissues the pressure of oxygen is low and the pressure of carbon dioxide is great. Oxygen therefore passes into the tissues and carbon dioxide passes into the blood. When the blood comes again in

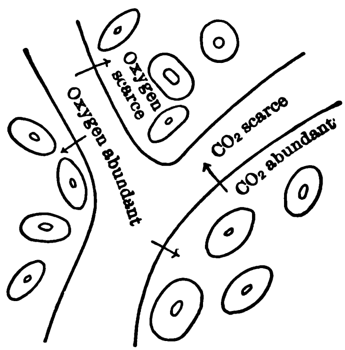



FIG. 17.—The passage of oxygen and carbon dioxide between the blood and the lymph in the tissues.

communication with air it gives up this carbon dioxide and receives a fresh supply of oxygen (Fig. 17).

**Respiratory Organs in Aquatic Animals.**—In aquatic forms such as lobsters, oysters, and fish the membrane that has been specialized for breathing is located on the surface of the gills (Fig. 18). The gills lie on each side of the body so near the surface that water can continually bathe them. They consist usually of a feathery outgrowth, or of two double flaps, covered with a very thin membrane.

**Relation Between the Blood and the Gill Membrane.**—Immediately under this membrane is a network of blood vessels with very thin walls, which connect the gill surface with every other part of the body. The air

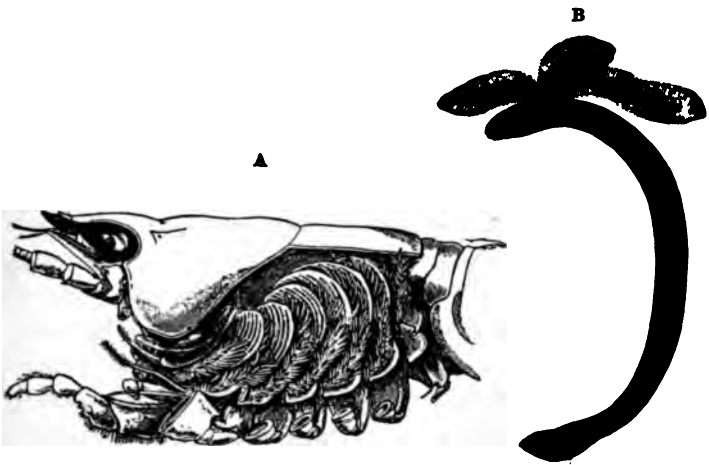



FIG. 18.—*A*, Gills of a crayfish exposed by cutting away the shell. (From Hertwig.) *B*, Larval form showing external gills. (From Hertwig, after Sarasins.)

in the water is separated from the blood by only the thin gill surface and the walls of the blood vessels. By osmosis, any gas in solution in the water can find its way into the blood and any gas in solution in the blood can find its way into the water. Relative pressure governs the process. As in one-celled animals, oxygen passes into the blood, for its pressure is greater in the water than in the blood; and carbon dioxide passes into the water, for its pressure is greater in the blood than in the water.

**Situation of the Moist Membrane.**—If one of these

animals were taken from the water and left exposed to the air, it would die for lack of oxygen, although there is such a large proportion of oxygen in the air, because oxygen can pass through a membrane only when the membrane is moist. In these animals, the membrane is situated practically on the outside of the body. It is kept moist by the water in which they live, but it would soon become dry and hard if exposed to the air. In animals not surrounded by water the membrane is protected by being situated in a moist chamber so far removed from the surface that it can not dry out. In insects it lines branching tubes; in other land animals it is developed into special organs called lungs.

**Respiratory Organs in Land Animals.**—Each lung is like a bunch of hollow grapes, with very thin skins. Each grape-like hollow is filled with air and is called an air cell. The thin skin is an elastic membrane in which is a network of tiny blood vessels. The air inside the air cells is thus separated from the blood in the blood vessels by a thin, moist membrane which can not grow dry because the lungs are situated in a moist chamber. Oxygen from the air inside each air cell can pass into the blood through the lung membrane as easily as it passes from water into the blood of the fish through the gill surface.

**Mechanism for Bringing Air in Contact with the Membrane.**—Lungs are so far removed from the surface of the body that a special mechanism is necessary to bring the air into the air cells in contact with the lung membrane. This mechanism is beautifully developed in human beings but it is not peculiar to them. It

might be studied to advantage in a cat or a dog, for the conditions are similar.

How does the air get inside the air cell? Each little air cell has a tiny tube opening into it which in turn opens into a larger tube and this into a still larger tube until we find that the whole mass of air cells in each lung opens into one large tube (Fig. 19). The tubes from the two lungs unite to form the trachea or windpipe (Fig. 20). Air that finds its way into the windpipe thus has free access to each little sac. As the behavior of the lungs, as a whole, is only the concerted behavior of all the cells, we may think of each lung as a hollow bag, a single enlarged air cell (Fig. 25, L).

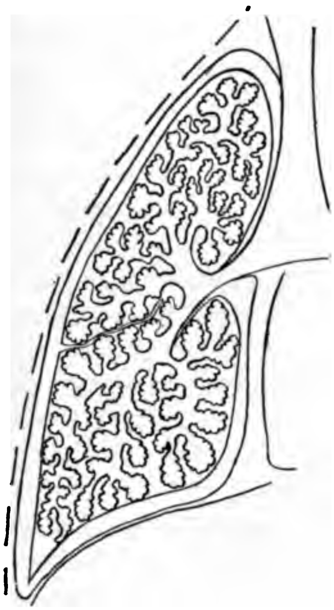


FIG. 19.—Air cells and bronchial tubes.

What makes the air go into the lungs? It is again a case of air pressure. If the pressure of the air is greater outside than inside the air rushes through the windpipe into the lungs; if it is greater inside than outside the air rushes out. This occurs at fairly regular intervals and is due to a rhythmical change in the pressure of the air within the lungs.

**Respiratory Muscles.**—What causes the alternate

change in pressure? It depends upon the situation of the lungs in the body. If we disregard the legs, arms, and head, the body is like a barrel. The hollow space inside contains various organs busy with the life proc-

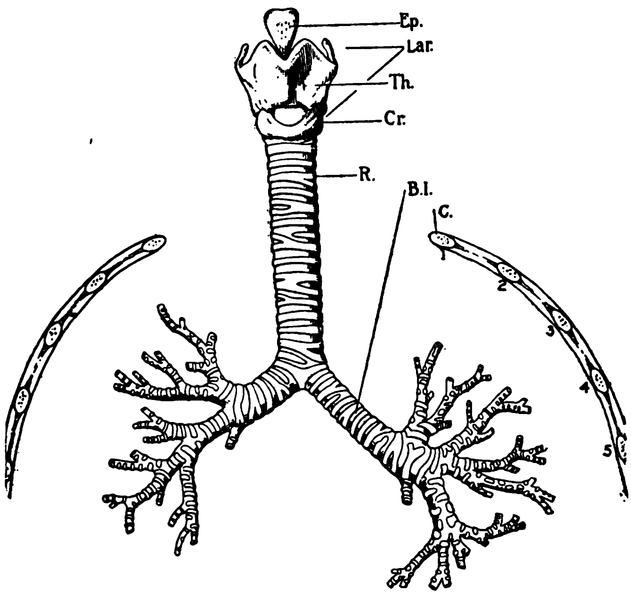



FIG. 20.—Front view of trachea and its branches. *Ep.*, Epiglottis; *Lar.*, Larynx; *Th.*, Thyroid Cartilage; *Cr.*, Cricoid Cartilage; *R.*, Ring of Cartilage; *B.l.*, Left bronchus; *C.*, Chest wall and ribs. (From Fitz.)

esses. In higher animals this cavity has a partition stretched across it. This partition regulates to a great extent the pressure in the lungs. It is not an immovable partition, but one that is capable of a great deal of activity. It is made of a muscle called the diaphragm in which the fibers are arranged like the radii of a

circle (Fig. 21). As each fiber contracts, the entire circle becomes smaller. When the fibers are relaxed the

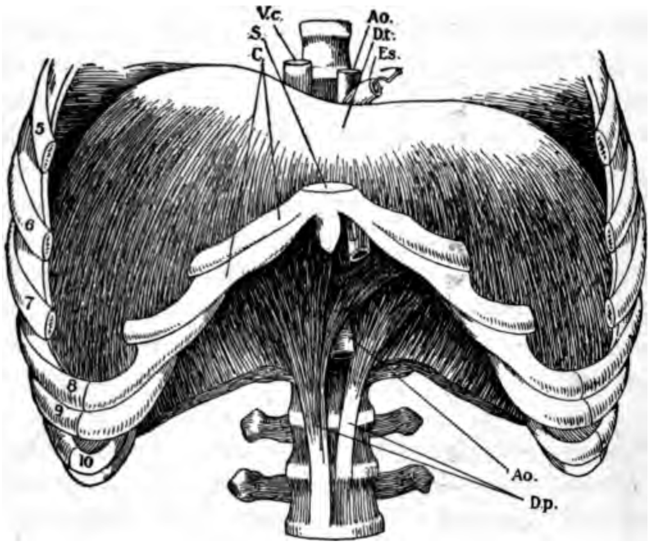



FIG. 21.—Front view of diaphragm and its attachments. *V.c.*, Vena cava; *S.*, Sternum; *C.*, Cartilages of ribs: *Ao.*, Aorta; *D.t.*, Central tendon of diaphragm; *Es.*, Œsophagus; *D.p.*, Pillars of diaphragm. (From Fitz.)

diaphragm is too large to make a flat partition across the barrel-like body, and we should expect it to hang down, but apparently against the laws of gravity it hangs up (Fig. 22, A). When the fibers contract the diaphragm flattens out and the upper cavity becomes longer than it was before (Fig. 22, B).

At the same time the muscles in the outside wall of this cavity contract and lift the ribs. Because of the peculiar shape of the ribs, the cavity becomes larger both

from side to side and from back to front when they are lifted (Fig. 23 and 24).

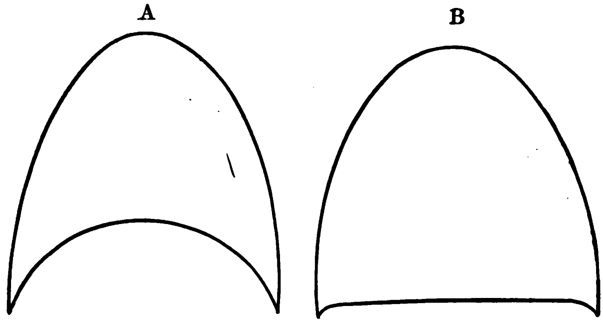



**Fig. 22.—Diagram illustrating the position of the diaphragm, *A*, when relaxed; *B*, when contracted.**

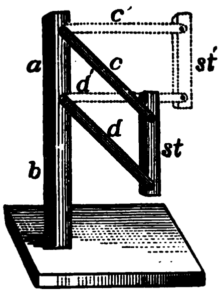



**Fig. 23.—Diagram illustrating the dorso-ventral increase in the diameter of the thorax when the ribs are raised. (From Martin.) *ab*, vertebral column; *c*, *d*, two ribs in expiration; *c′*, *d′*, their position in inspiration; *st*, sternum in expiration; *st′*, sternum in inspiration.**

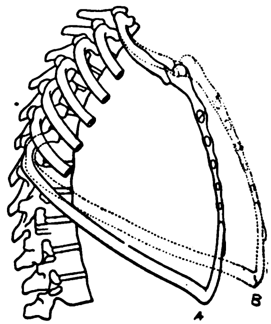



**Fig. 24.—Diagram illustrating the position of the chest in *A*, expiration and *B*, inspiration. (From Fitz.)**

These muscles are stimulated when there is an excess of carbon dioxide in the blood. They therefore con-

tract rhythmically and involuntarily. By their contraction the upper cavity is automatically increased in size in every direction.

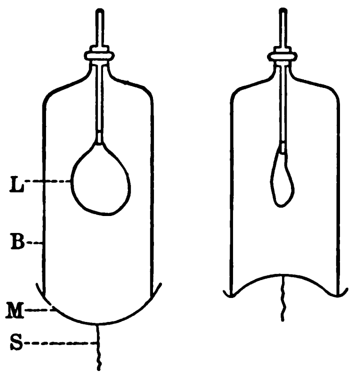


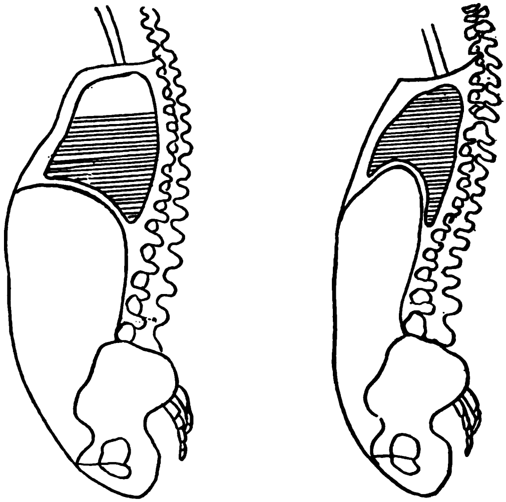

FIG. 25.—Diagram of apparatus to illustrate the effect of the position of the diaphragm on the lungs. *B*, bottle with bottom removed; *M*, flexible elastic membrane pulled by string, *S*; *L*, an elastic bag representing the lungs. It communicates with the external air by a glass tube fitted air tight through a stopper.

**Inspiration.** — The lungs are situated in this cavity and their delicate elastic bags respond to every change in the size of the cavity (Fig. 25). As the cavity becomes larger they become larger and the pressure of the air inside the lungs becomes less than the pressure outside. Immediately the air from the outside rushes through the windpipe into the lungs until an equilibrium is established. This process is called inspiration (Fig. 26, A).

**Expiration.**—When the muscles contract the reverse happens. The chest cavity contracts, the lungs become smaller, the air in the lungs becomes denser than the air outside, and passes out. This process is called expiration (Fig. 26, B).

**Effect of the Elasticity of the Lungs on the Diaphragm.**—As the air goes out, the lungs, which were stretched by the incoming air, tend to resume the smallest area. They push away from the diaphragm with a force equal to their elasticity so that the pres-

sure above the diaphragm is slightly less than the atmospheric pressure and consequently than the pressure



A B

FIG. 26.—Diagram to show the position of the sternum, diaphragm and abdominal wall in *A*, inspiration and *B*, expiration. The shaded area represents the stationary air, the unshaded area in *A*, the increased air space in inspiration.

below it. This causes the peculiar behavior of the diaphragm in hanging upward.

**Phraseology.**—The word respiration is used sometimes to refer to inspiration and expiration, and sometimes to the passage of gases through a membrane. To prevent confusion the passage of gases through a membrane has been called internal respiration, and the movement of the chest external respiration, but it seems clearer to restrict the word respiration to the essential process that occurs in all animals and reserve the words

inspiration and expiration for the special process that brings the gases in contact with the membrane occurring only in higher animals.

**Hygiene of Respiration.**—There is not so much difference as is ordinarily supposed between fresh air that is taken into the lungs and impure air that is given off;

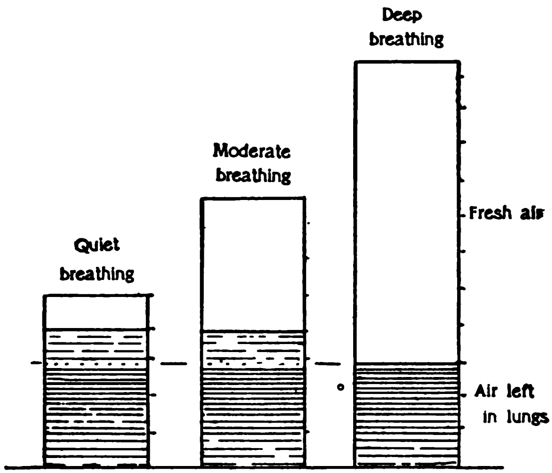



FIG. 27.—Diagram showing the relative amounts of fresh and stale air in the lungs at different depths of breathing. (From Fitz.)

the one contains about 20 per cent. of oxygen and but a trace of carbon dioxide, the other about 16 per cent. of oxygen and 4 per cent. of carbon dioxide. Four parts out of every hundred do not seem a large proportion of carbon dioxide, and yet this air is utterly unfit to be breathed in again, for the body is unable to get from it sufficient oxygen for its nourishment. In addition, this air is directly poisonous, for it contains poisonous substances from the body and in many cases disease germs.

The air cannot be entirely forced from the lungs. Even after the most forced expiration some air will still remain in them (Fig. 27). If this air is not frequently and thoroughly changed it will make an excellent medium for the growth of disease germs. Most disease bacteria do not thrive well in the presence of oxygen, but thrive admirably in its absence. People therefore who practice collar bone breathing exclusively are apt to leave the lower part of the lungs unused (Fig. 28).

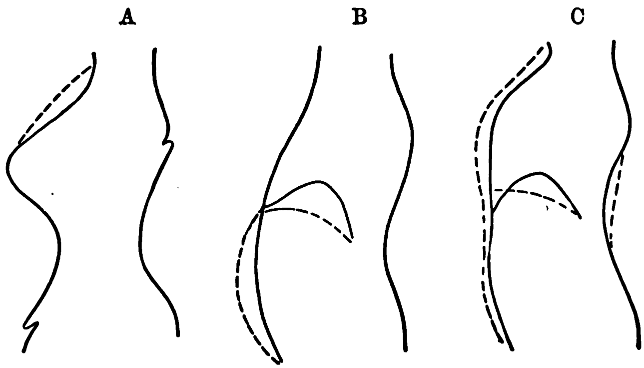



FIG. 28.—Types of breathing. *A*, corsetted figure, clavicular or collar bone breathing; *B*, male figure, abdominal breathing. Pressure of clothing and faulty position impedes expansion of the chest. *C*, figure properly posed and free from constriction. (After Coleman.)

They succumb much more easily to tuberculosis than those who breathe deeply.

Diaphragmatic breathing may be cultivated by simple exercise. Place the hands beside the lower ribs on each side of the body and force the ribs out against the hands. This will enlarge the chest cavity and air will enter. It is not necessary to suck in the air. The lungs are passive. They need not be considered, for they have

no power of initiation whatever. In order to improve the mechanism of inspiration all that is necessary is to strengthen the muscles which control the enlargement of the chest cavity. If at the same time the throat and jaw are relaxed the air will pass in and out easily and the voice will improve in quality. Few people use the voice as it should be used. Either they breathe improperly or they contract the muscles of the throat, tongue and jaw; or perhaps both. For purely æsthetic reasons it is worth while to cultivate a good speaking voice, for hygienic reasons it is even more important. A large amount of the wear and tear of our modern life comes from the unpleasant noises to which we are subjected. An unpleasant voice which must be heard from morning till night will rasp the nerves of the strongest person. Even though he may be unconscious of it, it will also react on the nerves of its possessor, for a rasping voice usually means a rasped throat and an undue call upon nervous energy. The beautiful voice of Sara Bernhardt, which even in a whisper reaches without effort the utmost limit of the largest theatres, is due not so much to a natural gift as to her patient cultivation of a wonderful diaphragm and of the power of relaxation. For the sake of improving the voice, of avoiding disease and of strengthening the whole body, it is worth while to cultivate the muscles which control inspiration and provide the preliminary condition for effective respiration.

**Summary.**—When an animal breathes, oxygen passes into its body and carbon dioxide passes out. All living animals have the whole or a part of the body covered

with a moist membrane. When a gas comes in contact with this membrane the freely moving particles of the gas pass through the spaces between the particles of the membrane.

In one-celled animals (1) The membrane covers the entire body surface. (2) Oxygen is dissolved in the water which continually bathes the surface. (3) This oxygen is carried to all parts of the body by the constant circulation of the protoplasm and enters into various chemical actions that finally result in the formation of carbon dioxide. (4) The carbon dioxide passes off into the water. This simple process has become complicated in higher organisms by certain peculiarities of development.

In many-celled animals the membrane is located in a definite place and the oxygen passes first into the blood. The blood carries it to all parts of the body and brings back carbon dioxide that it receives along its way.

The passage of oxygen into the blood and the passage of carbon dioxide into the water are independent of each other. In neither case can an equilibrium be established because the incoming oxygen is continually passing from the blood into the cells where it is used, and the outgoing carbon dioxide is continually passing from the cells where it is formed into the blood, so that in the blood the pressure of oxygen is kept continually less and the pressure of carbon-dioxide is kept continually greater than in the water outside.

In higher animals the membrane is far removed from the surface of the body for protection. A complicated mechanism is therefore necessary to bring air in contact

with the membrane. By a contraction of the diaphragm and of the muscles that lift the ribs, the chest cavity is enlarged. Inspiration occurs and fresh air is brought in contact with the lung membrane. When the muscles relax the cavity becomes smaller, expiration occurs, and the impure air is removed from contact with the membrane.

These processes do not happen by accident. Neither do they happen because we need them to happen. Every phase of the process of respiration is governed by a definite law. A gas always passes in the direction of the least pressure. In accordance with this law we will get the oxygen that we need if we do our part by seeing to it that the air about us is reasonably pure and that our muscles are strong enough to keep a good supply in contact with the lung membrane. But if we do not do our part, if, for example, we sit in an ill-ventilated room, we will not get the oxygen that we need. The law will act whenever gases are in contact with the membrane, but from vitiated air not oxygen but poisons enter the body.

The health of the entire body is dependent upon respiration. Give the healthy body plenty of oxygen and if it is not abused in any way it will probably remain healthy. Deprive the body of oxygen and it cannot remain healthy.

## CHAPTER III

## ASSIMILATION

**Steps in the Process.**—Living matter has the power to take in substances called foods and out of them to manufacture new living matter. The process by which foods are converted into the body substance is called assimilation.

Broadly the word includes all the steps in the process. We must therefore consider (1) The nature of food. (2) The way it is taken into the body. (3) The way it is made fit for the use of the body. (4) Its transportation to all parts of the body. (5) Its conversion into protoplasm and other unstable substances. (6) The elimination of waste materials. In this broad sense respiration, which provides much of the oxygen that is used in the manufacture of protoplasm and in the oxidation of wastes, and circulation, which carries substances from place to place in the body, are phases of assimilation. In this chapter we shall confine our attention to the assimilation of the food that we eat.

**Nature of the Process.**—It is clear that young animals must assimilate food, for they could not grow were it not for the addition of new material. But why should an animal continue to form new protoplasm after it has reached its full size?

The body is like a steam engine. Heat furnishes it with the power to move. This heat comes from chemical action. Whenever an animal moves, protoplasm, or some other unstable compound, splits into simpler substances and sets free heat. This heat causes other compounds to disintegrate, or simple substances to combine, until, through a series of chemical changes all of which set free heat, the food is converted into new complex compounds which replace the old ones that have split up, and wastes are formed which are given off from the body through an excretory organ.

Were it not for the assimilation of food the body would waste away as a result of activity. The more active the body then the more food is necessary. A laborer must eat more to keep the body in good condition than a bank clerk; and a growing child must eat more in proportion than a man, for the child's food must not only replace what is lost through activity but it must provide for growth.

**In One-Celled Animals.**—Assimilation is a universal process. It occurs in all organisms. With the compound microscope we may see one-celled animals take in food and give off wastes. The food surrounded by a drop of water passes directly into the protoplasm and the part that is unfit for use is eliminated through a weak spot in the body wall. This material never becomes part of the body, and it must not be confused with waste from the protoplasm. The nutritive part of the food is carried about in the circulating stream until it is converted into protoplasm. Waste from disintegrated protoplasm leaves the body through a pulsating vacuole,

a clear spot that alternately appears as it becomes filled with fluid and disappears as the fluid is emptied into the water outside.

**In Many-Celled Animals.**—The simple process in one-celled animals has all the essential features that characterize higher forms. In many-celled animals an organ is set apart for the reception of food. As the cells in the young animal begin to develop they become arranged in the form of a hollow sphere. At one point on the surface of the sphere the cells push in until they reach the opposite surface. This structure, called the gastrula, is bag-like. The wall is made of two layers of cells and the cavity opens to the outside by a single opening. The cells on the inside soon grow different from those on the

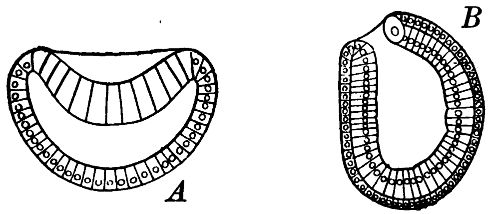



FIG. 29.—Formation of gastrula. (From Hertwig, after Hatschek.)

outside and become adapted to the assimilation of food. This is the primitive digestive tract (Fig. 29).

A great number of animals are still in the gastrula stage. Though they differ widely from each other, they are classed together, for they have one characteristic in common. The single cavity in the body is adapted to the assimilation of food and it has but one opening to the outside. Through this opening food enters and unfit

material passes out. The food is made fit for use in the cavity, passes into the cells lining the cavity and thence to all parts of the body. In most of these animals the cavity is bag-like (Fig. 30 A), but in jellyfish it is a well-defined tube (Fig. 30 B). This tube-like charac-

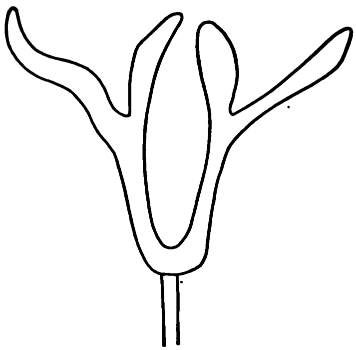


**Fig. 30 A.—Digestive tract of the hydroid. (See Fig. 36, A.)**

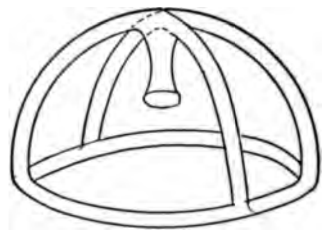


**Fig. 30 B.—Digestive tract of the jellyfish. (See Fig. 36, A.)**

ter is a marked characteristic of the alimentary system in all higher animals and gives rise to the name alimentary canal that is often used to designate this organ of the body.

**The Complete Digestive Tract.**—In the next group of animals a further development occurs which also becomes an important characteristic of all higher animals. The tube develops a second opening to the outside. Food then enters through one opening and refuse passes off through the other. Special organs exist for the eliminating of waste substances which result from the splitting up of protoplasm. In almost all animals, then, the digestive system is a tube open at both ends to the

outside. The shape of the tube, its length, and the way it lies in the body differ in the various groups, but it bears a close relation to the shape of the animal and to the character of its food.

**Variations in Development.**—The starfish is a flat, five-rayed animal. The tube passes through the animal from the dorsal, or upper, to the ventral, or under, side, and is very short. It swells out into two

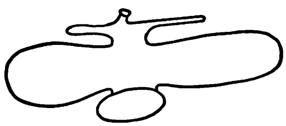


FIG. 31.—Digestive tract of the starfish (section). (See Fig. 36, B.)

enlargements or stomachs, each of which has five pouches corresponding to the five rays (Fig. 31).

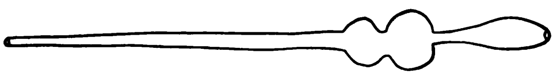


FIG. 32.—Digestive tract of the earthworm. (See Fig. 36, B.)

The lobster and the earthworm are elongated. The tube is correspondingly long and straight, and the stomachs comparatively small (Fig. 32, Fig. 33). In

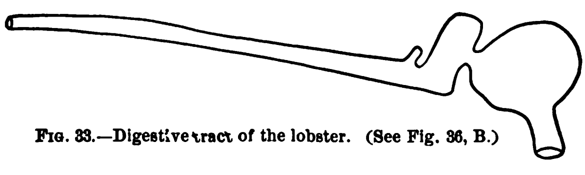


FIG. 33.—Digestive tract of the lobster. (See Fig. 36, B.)

clams as the tube is too long to pass directly through the body, it becomes twisted on itself (Fig. 34). In

higher animals the tube is more highly developed. The enlarged stomach is sharply defined; the tube is

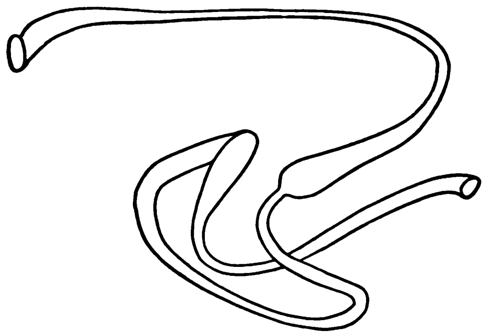


FIG. 34.—Digestive tract of the clam. (See Fig. 36, C.)

very long in proportion to the length of the body, and is consequently very much twisted on itself (Fig. 35,

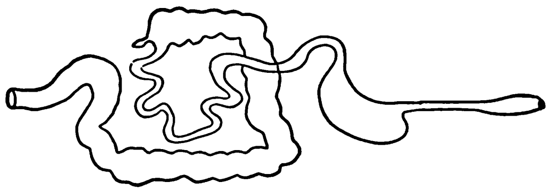


FIG. 35.—Digestive tract of a vertebrate. (See Fig. 36, C.)

Fig. 36); and special glands are developed from it which manufacture special digestive fluids.

**Diet of Animals.**—The diet of animals varies greatly. Some animals live entirely upon plants, others eat only the flesh of other animals, still others eat a mixture of plant and animal tissues. Gradually animals have become adapted to the diet which in the beginning was adopted either through choice or through necessity and

which proved best suited to their needs, and they could not now exchange diets. Grain-eating animals have teeth fitted for grinding and a well-developed system

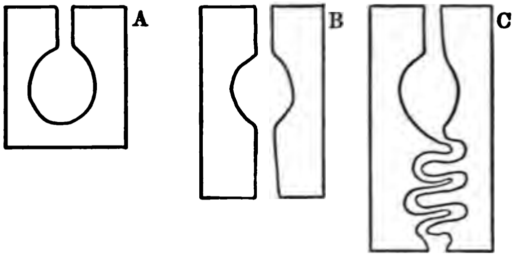



FIG. 36.—Diagram to illustrate the development of the alimentary canal in the advance from lower to higher forms.

for digesting plant tissues. Flesh-eating animals have teeth fitted for tearing flesh and crushing bone, and a less highly developed system for the digestion of flesh. Animals that eat a mixed diet have both kinds of teeth and a digestive system which in size and structure lies between the two extremes.

**The Five Food Substances.**—Although diets vary, we find that the foods that animals eat differ only superficially. No matter what an animal eats there are contained in it only the five food substances: water, salts, carbohydrates, hydrocarbons, and proteids. These all animals must have.

**Water.**—Water is contained to a greater or less extent in everything that we eat. It is possibly the most important of the food substances, for not only does it act as a food but also as a solvent of other food substances. These can not enter the cells unless they are dissolved, for only liquids or gases can pass through the

cell-walls. As water is a liquid it passes through easily and carries with it everything it holds in solution. In its natural state water always contains substances in solution which are good for the body. We should therefore drink large quantities of it, but we should be careful that it is pure and uncontaminated by disease germs.

**Salts.**—Salts are contained in the water that we drink and in almost everything that we eat. Table salt, or sodium chloride, is the most important of these, for it is constantly lost from the body through perspiration and other excretions, and it is necessary to the composition of the blood and the maintenance of the right proportion of water in the tissues. Animals that live on grains poor in salt often travel many miles in order to reach salt licks. As salts are so readily dissolved in water, they undergo no change before entering the cells of the body.

**Carbohydrates.**—Carbohydrates include cellulose, starch and sugar. They are manufactured by plants from water and carbon dioxide. They are therefore found in varying amounts in most plant tissues. As animals eat the plant tissues they are also found in the bodies of animals. They consist of carbon, hydrogen and oxygen in such proportions that there is always twice as much hydrogen as oxygen. They are called carbohydrates, a name that means carbon watered, because two parts of hydrogen and one of oxygen form water.

**Hydrocarbons.**—Hydrocarbons include all fats and oils. They are found in the tissues of both plants and animals. They contain carbon, hydrogen and oxy-

gen, but there is more than enough hydrogen to form water. The excess of hydrogen is responsible for the name hydrocarbon.

**Proteids.**—Proteids are practically identical with dead protoplasm. We eat them whenever we eat the tissues of plants or animals. In animals there is a larger proportion of proteids and fats and a smaller proportion of starches than in plants. Chemical analysis shows that proteids are composed principally of carbon, hydrogen, oxygen and nitrogen. In addition they may contain traces of sulphur and phosphorus. They are especially important because of the nitrogen that they contain. Nitrogen is absolutely necessary to the manufacture of protoplasm, and as animals can not use free nitrogen from the air they can obtain it only from the proteids that they eat.

**Necessary Proportions of Food Substances.**—Without proteids the body would starve very quickly, but it could subsist for a considerable period without starch or fats. These substances are especially useful because they are completely oxidized in the body and consequently set free an enormous amount of heat. In general, the amount and character of the food required by man depends on the amount of work that he does. We find that although the diet differs in different countries, men who do the same amount of hard work eat approximately the same quantity of food made up approximately of the same proportions of carbohydrates, hydrocarbons and proteids.

**Nutriment in Food Stuffs.**—*Cereals* furnish more nutriment in proportion to weight and cost than other

foods. Wheat, oats or corn with some form of fat forms an almost perfect food, that is, a food which contains the proper proportions of proteids, fats and starches. Bread and butter lack only a small amount of proteid. Most breakfast foods are very bulky in proportion to the amount of nutriment they contain.

*Vegetables* are especially valuable because they contain large quantities of sugar and starch. Some of them are rich in proteid. They are valuable also because they contain salts and cellulose. Cellulose is not nutritious but it is useful mechanically, for through its bulk it aids the movement of the food through the canal.

White potatoes, sweet potatoes, tapioca, bananas, are rich in starch; melons, grapes, beets, in sugar; peas, beans, peanuts, nuts, in proteids; olives, nuts, in fats; cabbages, turnips, in cellulose.

*Milk* and *Eggs* are very nearly perfect foods. Milk contains water, salts, proteids, fats and sugar. Eggs lack carbohydrates.

*Meat* is valuable because it contains a great deal of proteid that is more easily digested than plant proteid.

*Condiments* such as spices, mustard, ginger, pepper, stimulate the appetite but contain no nutriment.

*Beverages.*—Tea and coffee are stimulating but not nourishing. Cocoa and chocolate have a slight food value on account of the fat they contain. These substances are not necessarily harmful if taken in moderation with food, but they all contain a powerful drug which is distinctly harmful if taken habitually in too great quantities. Alcohol may be oxidized in the body, and for this reason there has been some discussion as to

its food value. It is so very harmful in its effects upon the nervous system, however, that it can not properly be considered a food. Water is the most wholesome beverage.

**Digestion.**—When food is swallowed it is not really inside the body although it is in the alimentary canal. It is like a piece of dough that has accidentally dropped into the upright tube of an old-fashioned cake pan (Fig. 37). In order to get into the body it must pass through the cells that form the wall of the canal. As starches, fats and proteids are insoluble, they must be made soluble before they can pass through the wall, that is, they must be digested. This is accomplished through the activity of certain complex and very unstable compounds called enzymes, or ferments, which are produced by living cells.

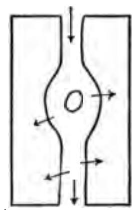


FIG. 37.—Diagram to illustrate the relation of a particle of food in the alimentary canal to the body. It does not enter the body until it has passed through the wall of the canal in the direction of the horizontal arrows.

**Enzymes.**—There are a great many enzymes all of which have certain characteristics in common. They have no power to initiate a change, but they are able to hasten, or retard, a chemical, or physical action, so that it is able to take place under conditions which would ordinarily render it impossible. They act at very low temperatures and in exceedingly small quantities without being used up.

**Enzymes in the Digestive Juices.**—The three classes of substances to be digested have three corresponding

classes of enzymes to act upon them. One changes the starches, another the proteids, and the third the fats, into soluble substances which can readily be absorbed. These enzymes are found in the various digestive juices of the body. The saliva, a digestive fluid found in the mouth, contains an enzyme which changes starch into a soluble sugar called maltose. In order that it may have time to do its work starchy foods should be thoroughly chewed. The other food substances are not changed by saliva, but they are moistened and are consequently swallowed more easily.

The gastric juice which is secreted by small glands in the wall of the stomach also contains only one enzyme, pepsin. Pepsin changes proteids into soluble peptones but has no effect on starches and fats. The pancreatic juice contains three enzymes. The most important of these is called lipase. It changes fat into soluble fatty acid and glycerine. The other two enzymes act upon starch and proteid that escape digestion in the mouth and stomach.

**Reversible Action of Enzymes.**—Very curiously the action of enzymes is reversible; that is, if an enzyme changes starch into sugar, it also changes sugar into starch. These actions take place simultaneously, and result in an equilibrium, or a condition of balance. Whenever there is an increase or a decrease of either substance the equilibrium is disturbed, and the action becomes more vigorous in one direction than in the other.

If, for example, there is a surplus of starch, the starch is transformed into sugar more rapidly than the sugar into starch.

**Enzymes in the Tissues.**—These enzymes are not confined to the digestive juices. If they were, the change of food substances into protoplasm might be more complicated than it is. They may exist in any part of the body. Through their reversible action soluble substances may be changed into proteids, fats or starch, and stored in any part of the body; or proteids, starch or fats may be changed into soluble form and carried by the blood to other parts of the body where they may be used by the protoplasm. Large quantities of proteids are stored in the muscles and in the blood; starch in the muscles and in the liver; and fat in any part of the body, though it is found in quantities most often just under the skin. In cases of starvation, these stored substances may be drawn upon, the fat first, and later the starches and proteids.

**Passage of Food Through the Canal.**—Through a series of muscular contractions, food taken into the mouth is forced to pass down the canal. The tongue and cheek muscles help to hold the food between the teeth while it is chewed; they then squeeze it into the cavity at the back of the mouth, over the top of the windpipe which is closed by a swinging lid, into the œsophagus, which relaxes to receive it. The œsophagus then contracts behind the food and relaxes before it, until it reaches the stomach, a small pear-shaped bag, which holds about three pints when it is moderately distended.

During the first hour and a half the opening into the small intestine is very small and only the dissolved starches and proteids pass through. Later the opening becomes larger and other substances pass through easily.

water and urea. Carbon dioxide and water vapor, by osmosis through the lung tissue, pass from the blood to the air in the lungs and are removed from the body. Solids are not able to do this. Special organs therefore

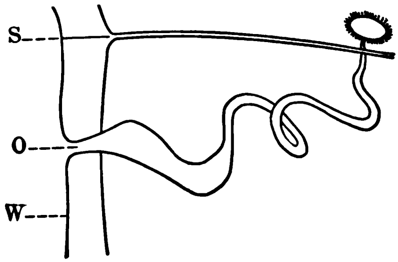



FIG. 39.—Excretory organ of the earthworm. *W*, body wall; *O*, opening to the outside; *S*, septum. The tube passes through the septum and opens through a funnel-shaped ciliated mouth into the body cavity.

prepare them for removal and they leave the body in solution in water (Fig. 39).

**The Kidneys.**—The kidneys, two reddish brown, bean-shaped bodies, lie on each side of the spinal column under the lowest ribs (Fig. 40). Large arteries enter them and become subdivided into small capillaries which penetrate every part of the tissue. Later these reunite into veins which carry the blood from which the waste has been removed back to the heart. The capillaries gather together in small masses, each of which becomes surrounded by a cup which opens into a tube closely wrapped about by capillaries (Fig. 41). Through the thin walls of these capillaries water carrying wastes, principally urea in solution, passes into the cups or directly into the tubes. The tubes unite and empty eventually into the bladder through a large tube called

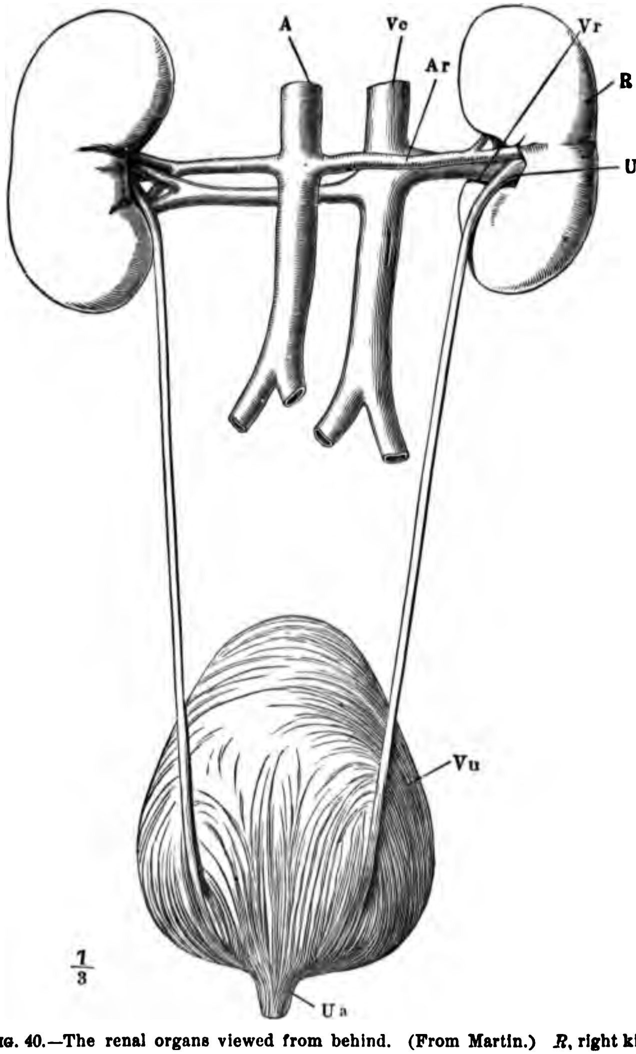



FIG. 40.—The renal organs viewed from behind. (From Martin.) *R*, right kidney; *A*, aorta; *Ar*, right renal artery; *Vc*, inferior vena cava; *Vr*, right renal vein; *U*, right ureter; *Vu*, bladder; *Ua*, commencement of urethra.

the ureter. The amount of water that is removed from the blood in this way depends on the amount that has been drunk. Normally it is about three pints daily.

**Urea.**—Urea ($N_2H_4CO$) is formed by the splitting up of proteids. It therefore contains a large amount of nitrogen. As it is an incompletely oxidized substance, the body does not get so much heat in proportion from the splitting up of proteids as it does from the splitting of fats and starches, which give rise to water and carbon dioxide, completely oxidized substances.

**The Sweat Glands.**—The sweat glands are very tiny (Fig. 42). They are scattered over the body in the layer of fat immediately under the skin. The " pores " are the openings of minute ducts that lead from them to the surface of the skin. Their secretion is composed normally of water, salt and the products of the sebaceous glands; but if the kidneys fail to do their work properly the substances ordinarily secreted by them appear in the perspiration. The amount of the secretion may be a quart or more daily, depending on the activity of the kidneys, on the temperature and on the amount of exercise.

**Hygiene of Digestion.**—The hygiene of digestion is possibly more important than that of any other function. Many eminent physiologists and physicians attribute the majority of bodily ills to abuse of the digestive system. Not only must we have palatable food in sufficient quantities, but it must combine the right proportion of proteids, fats and starches. The thought alone of something that we particularly like causes the mouth to water. Exactly the same thing takes place in the

stomach when attractive food is eaten. The digestive juices are produced in larger quantities and in better quality, and the food has a better chance of being properly digested. This fact is often disregarded. Some people advocate uncooked food, but not only does cook-

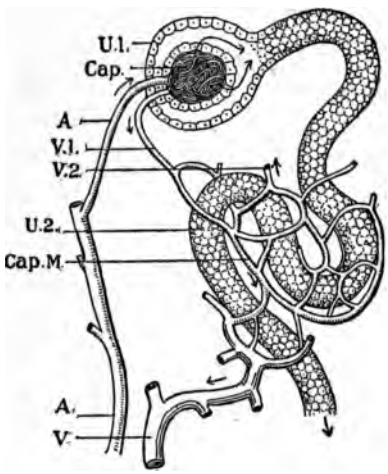



**Fig. 41.—Structure of kidney, showing the secreting mechanism. The arrows indicate the direction of the flow of the fluids. *U.*1., beginning of urinary tubule; *Cap.*, Tuft of Capillaries; *A.*, Artery; *V.*1., Vein to tubule; *V.*2., Vein from tubule; *U.*2., Urinary tubule; *Cap.M.*, Capillary mesh over tubule; *V.*, Vein. (From Fitz.)**

ing render meats and most vegetables more palatable, but it is a safeguard against disease germs. It is better to keep the body well than to cure it of disease. Healthful living, which includes proper care of the diet, will do much toward keeping the body in good condition, and often a change in diet will enable one to dispense with drugs that might otherwise be taken.

It is important that food should be properly chewed. In order that the enzymes may digest food they must come directly in contact with food particles. If large pieces are swallowed, the enzymes come in contact with

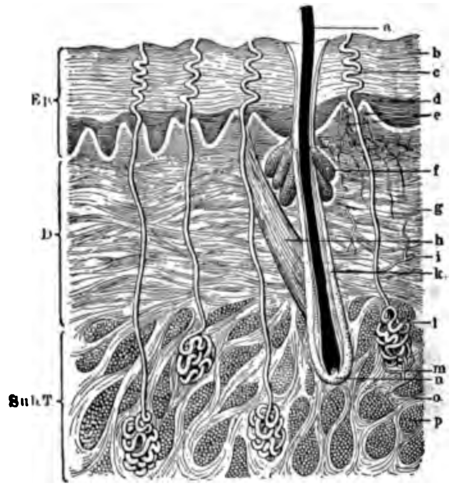



FIG. 42.—Section of skin highly magnified showing sweat glands. *Ep.*, Epidermis; *D.*, Dermis; *Sub. T.*, Subcutaneous tissue; *a*, Shaft of hair; *b*, Horny layer of skin; *c*, Duct of sweat gland; *d*, Papilla; *e*, Capillaries of papillæ; *f*, Sebaceous glands; *g*, Connective tissue; *h*, Erector muscle of hair; *i*, Artery; *k*, Hair follicle; *l*, Coil of sweat gland; *m*, Artery to sweat gland; *n*, Papilla of hair; *o*, Connective tissue; *p*, Fat. (From Fitz.)

the surface only. Only the outer surface will then be digested. Undigested masses are thrown into the intestine, fermentation takes place and poisonous substances are absorbed. Food should be chewed until it no longer has a specific taste and until it is a homogeneous mass.

Chewing keeps the teeth in good condition by providing them with exercise. Most dentists say that a

large part of their trade depends upon the fact that people chew their food insufficiently, or eat food that is too soft. Sudden changes of temperature from hot coffee to iced water, for example, may crack the enamel. The teeth should be cared for, otherwise they decay. They then not only cause great pain but they are not able to do their work well, which may result in serious indigestion or dyspepsia, and they become lodging places for disease germs.

Emphasis should be laid upon the fact that the body needs a large quantity of water to dissolve food and carry it throughout the body. Water should not, however, be taken in large quantities with meals, because it dilutes the digestive juice and renders it less effective. Neither should very cold water be taken at that time, as the digestive juices work only at certain temperatures. If water is taken immediately upon rising in the morning and an hour or two before meals the desire for it with the meals will disappear for the thirst is already appeased.

Bad cases of nervous indigestion and catarrh of the stomach have been cured by the simple expedient of drinking, an hour before breakfast, a quart of hot water containing a half teaspoonful of salt and the juice of half a lemon. The large quantity of water washes clean the walls of the alimentary canal so that they are more fit for the absorption of the digested food.

**Summary.**—Every movement of the body is accompanied by the disintegration of protoplasm, or other complex and unstable substances. These substances are replaced by new substances made through the assimila-

tion of food. The series of chemical changes that occur in the process set free heat, which furnishes the motive power for the activity of the body. The foods fall into five classes: water, salts, proteids, fats and starches. The last three must be digested, or made soluble, before they can be assimilated. This is accomplished through the activity of enzymes manufactured by the protoplasm. In the lowest animals the entire process of assimilation occurs in a single cell; in higher animals a special organ is set apart for digestion which has the form of a tube of varying width open to the outside at both ends. A series of muscular contractions forces the food to pass through the tube. On the way, the food is acted on by enzymes, and the nutritious substances pass into the blood and are carried by it to every part of the body. Undigested material and material that can not be digested pass off from the other end of the tube. Wastes from the disintegration of protoplasm are given off through special excretory organs.

## CHAPTER IV

## CIRCULATION

**Necessity for Circulation.**—Assimilation and respiration are rendered effective through circulation. As new protoplasm may be made in any part of the body, oxygen and food products, the materials involved in its manufacture, must be transported throughout the body, and the wastes that result from its disintegration must be transported to a place from which they may be ejected.

**The System.**—In one-celled animals the circulation of the protoplasm within the cell suffices for the distribution of substances through the body.

In many-celled animals a special circulatory system is necessary, for substances taken in at a definite point must be transported to tissues which may be remotely situated. An elaborate network of tubes penetrate all the tissues. These tubes are filled with blood which is in constant motion, and through the blood the transfer of substances from place to place is effected.

**In Lower Animals.**—In the lower animals the tubes are few in number and their comparatively simple arrangement is determined by the shape and size of the animal and the arrangement of the various organs in its body. In starfish, for example, a blood vessel encircles the mouth and sends off a branch into each one of the

rays (Fig. 43), while in the earthworm two long tubes connected by a series of encircling rings run lengthwise in the body (Fig. 44).

**In Higher Animals.**—In higher animals the number

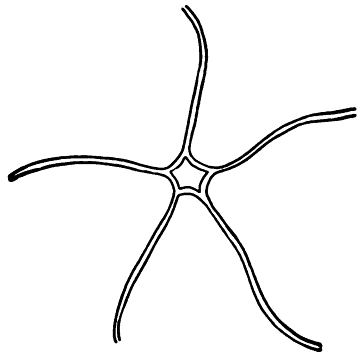


FIG. 43.—Diagram of the circulatory system of the starfish.

of tubes is greater and their arrangement is consequently more complex. There is a general similarity in all animals that have four limbs attached to a trunk. Minor details such as the branching of the vessels may vary, but

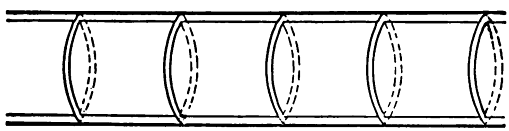


FIG. 44.—Diagram of the circulatory system of the earthworm.

even from a frog one can get a fairly good idea of their arrangement in man.

The most noticeable feature of the system is an enlargement called the heart. In very low animals it is a simple tube. In higher animals it begins as a tube but

its tube-like character is soon obscured, for it grows faster than the space in which it is situated and becomes twisted upon itself in such a way that four chambers are formed.

From the heart branch large tubes which become smaller and smaller through repeated division. The small tubes later reunite, forming larger and larger tubes which lead back to the heart. The blood is thus able to travel from the heart through the tubes to all parts of the body and back to the heart, making a complete circulation.

**Mechanical Factors which Control the Circulation.** (1) *The heart.* The passage of the blood through the body is controlled by purely mechanical features. The heart furnishes the motive power. It pushes the blood forward through the tubes by means of its rhythmical contraction. It is a hollow body divided by a partition into two unconnecting chambers each of which is subdivided into two connecting chambers called respectively the right and left auricle, and the right and left ventricle. Its walls are made entirely of short, powerful muscle cells so interlaced that they are strong enough to send the blood throughout the body and firm enough to

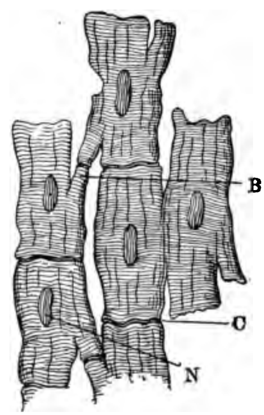



FIG. 45.—Muscle cells of heart. *B*, Connecting branch; *C*, Cement substance; *N*, Nucleus. (From Fitz.)

prevent its escape through them (Fig. 45). When the chambers are distended with blood the walls contract until they force the blood out, they then relax and allow another supply to come in (Fig. 46). This contraction

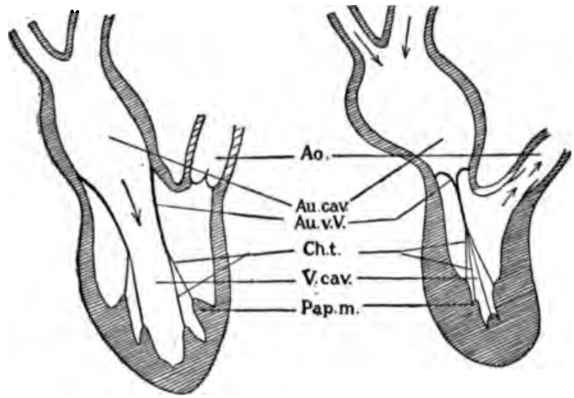



**Fig. 46.—Diagram of heart during relaxation and contraction.** ***A*, auricle contracting to fill ventricle; *B*, auricle filling, ventricle emptying into aorta. *Ao.*, Aorta; *Au.cav.*, Cavity of auricle; *Au.v.V.*, Auriculo-ventricular valve; *Ch.t.*, Chordæ tendinæ; *V.cav.*, Cavity of ventricle; *Pap.m.*, Papillary muscle. (From Fitz.)**

and relaxation cause the heart beat which can be felt on the left side of the chest. The thickness of the walls depends on the amount of work demanded of them. The auricles contract simultaneously and the blood passes into the ventricles. As this requires little force, the walls of the auricles are comparatively thin. The ventricles contract simultaneously and the blood is sent through the body. They exert greater pressure and their walls are correspondingly thick.

(2) *The valves.* The blood is kept flowing continu-

ously in one direction by valves. These are situated: (a) between the auricles and the ventricles, (b) between the ventricles and the arteries and (c) throughout the veins. The valve between the auricles and the ventricles is like a swinging door that opens in one direction only. It opens in response to the pressure of the blood, allows the blood to pass through, and then swings shut. The blood can not then pass back into the auricle. At the outlet of the ventricle there are three flat pockets which allow the blood to pass out of the ventricle, but when it attempts to return, they become filled with blood and swell out so that the opening is closed (Fig. 47). Similarly in the veins the valves open to allow the blood to pass toward the heart but close against its return. Without the valves, the flow in the veins would be backward, because of the diminution of pressure.

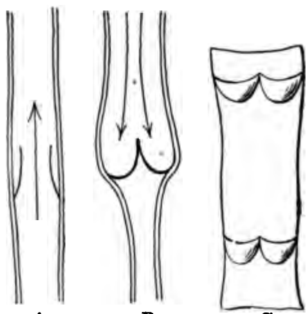



**Fig. 47.—Diagram of valves of veins.** *A*, valve opened by blood passing forward toward heart; *B*, valve closed by attempted return of blood; *C*, vein opened to show arrangement of valves. (From Fitz.)

(3) *The closed system.* The system is closed; that is, the irregularly branching tubes are so arranged that when the blood has been carried from the heart to all parts of the body it is gathered together and returned to the heart. The vessels through which the blood leaves the heart are tough, thick-walled, highly elastic tubes called arteries. They divide and sub-divide into smaller

and thinner-walled tubes which penetrate into every part of the body. The finest of these are the capillaries. In these the wall is made of a single layer of flat cells placed edge to edge. It is so thin that the blood is brought in close contact with the tissues and by osmosis gives up readily the nourishing substances it contains, and takes away the waste products. The capillaries unite to form larger tubes called veins, that bring the blood back to the heart. The walls of the veins are very thin, for little work is required of them. The pressure is reduced in the capillaries, and in the veins not enough is exerted to urge the blood onward. It is sucked back into the heart by the alternate change of pressure in the chest cavity due to the movements of expiration and inspiration.

The blood leaves the left ventricle through a large artery called the aorta, goes throughout the tissues and returns to the right auricle. From this it passes into the right ventricle. It leaves the right ventricle through the large pulmonary artery, goes to the lungs and thence back to the left auricle (Fig. 48). From this it goes to the left ventricle and is ready for another circuit. As the circuit through the body is much longer than that through the lungs, the left ventricle exerts more pressure than the right ventricle and its walls are correspondingly thicker.

(4) *Elasticity.* The blood vessels are extremely elastic. This quality causes the blood flow which in the arteries responds to the intermittent heart beat, to become steady by the time it reaches the capillaries. At every contraction of the ventricles blood is pushed into the two large arteries, which stretch to receive it. The

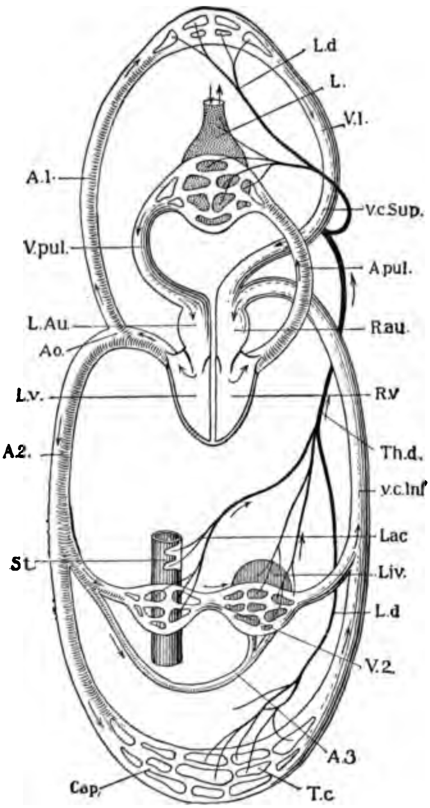



FIG. 48.—Diagram of the circulation of the arterial and venous blood and the lymph. *A.1.*, Arteries to head, arm and neck; *V.pul.*, Pulmonary vein; *L.Au.*, Left auricle; *Ao.*, Aorta; *L.v.*, Left ventricle; *A.2.*, Arteries to lower part of body; *St.*, Stomach and intestine; *Cap.*, Capillaries; *L.d.*, Lymph duct; *L.*, Lungs; *V.1.*, Veins from head, arms and neck; *v.c.Sup.*, Vena cava sup.; *A.pul.*, Pulmonary artery; *R.au.*, Right auricle; *R.v.*, Right ventricle; *Th.d.*, Thoracic duct; *v.c.Inf.*, Vena cava inf. (from lower part of body); *Lac.*, Lacteals; *Liv.*, Liver; *L.d.*, Lymph duct; *V.2.*, Vein from intestine to liver (Portal vein); *A.3.*, Artery to liver; *T.c.*, Tissue cells. (From Fitz.)

recoil of their elastic walls makes them press upon the blood and squeeze it forward. But before they have

squeezed it all out, the ventricles contract again and force in more blood, which again stretches them. Each new impulse sends in new blood, causing a succession of stretches in the artery as the column of blood passes on. This succession of stretches known as the pulse passes through the blood vessels much more rapidly than the blood itself. A heart beat is indicated by the beating of the artery on the wrist, for example, long before the blood forced out of the heart reaches there. As it is an accurate register of the heart beat it is useful to physicians in determining the rapidity of the heart beat.

(5) *Tone.*—Tone is often confused with elasticity, but in reality it is something quite different. It involves a variation in the size of the arteries, but it depends not on the mechanical stretching of their walls by the entrance of blood, but upon the sustained activity of the muscles composing the walls through which the tubes may become large or small at any given moment.

The walls of the arteries, especially the small ones, contain encircling muscle fibers; if the fibers relax, the opening becomes larger and more blood passes through; if they contract, the opening is smaller and less blood passes through (Fig. 49).

The tone of the blood vessels is extremely important, because by means of it the system of tubes is kept completely filled with fluid. If the blood vessels in the abdomen should enlarge to their utmost, it would take all the blood in the body to fill them and the other blood vessels would be empty. This would mean a cessation of circulation. But the tone is regulated in such a way that these

blood vessels do not all enlarge at the same time. When certain blood vessels dilate, certain others contract, so that the volume of blood is always slightly in excess of the capacity of the blood vessels. Elasticity is then called upon to make room for the excess. The supply of blood sent to a tissue is thus adjusted to the need of the tissue. The more active the tissue the more the vessels dilate and the more blood passes through. The power of the vessels to change their size also has an important effect on the temperature of the body, as we shall see later.

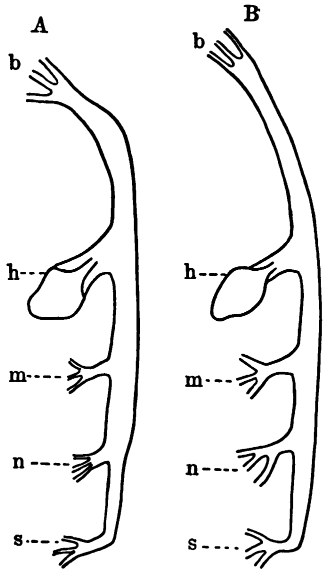


FIG. 49.—Diagram showing the relation between general arterial tone and the supply of blood to the brain. In *A*, the arterioles in organs *m*, *n*, *s*, are constricted, raising the general arterial pressure and forcing a large amount of blood through the brain. In *B*, they are dilated, lowering the general arterial pressure and diminishing the amount of blood sent to the brain. (After Hough and Sedgwick.)

**Composition of the Blood.**—The blood is largely composed of water. In it sodium chloride and other salts are dissolved. This salt solution holds in suspension several proteids and the red and white corpuscles. In it also are food for the tissues, secretions of various glands, and waste products of oxidation. Through the give and take of the tissues the food substances are present in the

blood in fairly constant amounts. If through excessive eating an excess of proteid is received, it remains in the blood in the form of the blood proteids until it is given up to the tissues for use. If there is an excess of sugar, it is stored in the liver temporarily until there is a deficiency in the blood. If there is an excess of fat, it may be stored in any cell, but especially in the connective tissue cells, where it is apt to become permanent. If there is a deficiency of these substances in

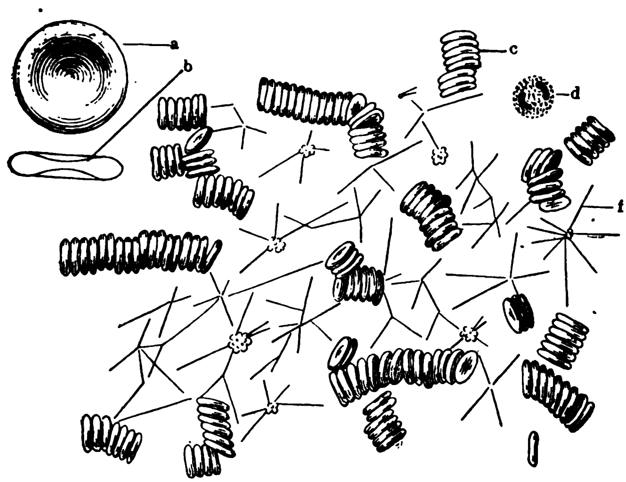



FIG. 50 A.—Coagulated blood highly magnified. *a*, Red corpuscle much enlarged; *b*, Cross section of red corpuscle; *c*, Rouleau of red corpuscles; *d*, White corpuscles; *f*, Fibrin. (From Fitz.)

the blood the tissues themselves waste away and supply the lack.

**The Red Corpuscles.**—Both red and white corpuscles are isolated living cells (Fig. 50). They resemble one-celled organisms, but they differ greatly from each other

in appearance and in work. Through a high-power lens the red corpuscles appear as flattened discs of a pale yellowish red. Their great number is responsible for the deep red color of the blood. This color is due to a substance they contain called hemoglobin which has a remarkable affinity for oxygen. Oxygen passes from the air in the lungs into solution in the blood, but the blood holds so little in solution that the body would die for lack of oxygen were there not some way of storing it. Hemoglobin holds oxygen in a loose chemical combination and acts as a storehouse. By means of it the blood keeps on hand a sufficient supply of oxygen to maintain a steady flow into those cells which are deficient.

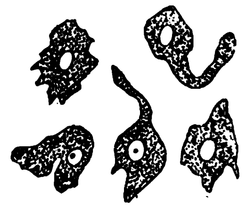


FIG. 50 B.—A white blood corpuscle showing ameboid movement. (From Fitz.)

**Relation between Oxygen and Hemoglobin.**—Oxygen never passes directly into the hemoglobin from the air in the lungs. It goes into solution first. While there, if it comes in contact with hemoglobin, a new substance called oxyhemoglobin is formed. This substance is extremely unstable. Oxygen and hemoglobin separate as readily as they unite and the oxygen goes into solution, never directly to the tissues. Combination and separation take place at the same time in accordance with the relative amount of oxygen in solution and in combination with hemoglobin. If at any given place there is an excess of oxygen in solution very rapid passage will take place into the hemoglobin in that vicinity.

If there is an excess in combination, the passage will be very rapid out of the hemoglobin.

**Oxygen Can Not Establish an Equilibrium.**—Theoretically an equilibrium tends to establish itself (1) between the oxygen in solution and that in combination with hemoglobin, (2) between the oxygen in solution and that in the air in the lungs, and (3) between the oxygen in solution and that in the cells; but practically no equilibrium is possible in these cases because oxygen is continually passing out of solution into the cells where it is used and into the hemoglobin where it is stored. The pressure of oxygen is thus kept low in the solution, in response to which oxygen passes into the solution from the outside air.

**Origin and Fate of the Red Corpuscles.**—The red corpuscles are formed in the red marrow of the bones and when very young they have a nucleus. As they mature they lose it, and in consequence they disintegrate very easily, usually in the spleen or in the liver. In high altitudes the rare air contains very little oxygen, but in compensation for its diminished flow into the blood the number of red corpuscles increases rapidly. As the amount of hemoglobin is increased, oxygen is removed from the solution faster than usual. It thus becomes more difficult to establish an equilibrium and the tissues have a better chance of getting from the rare atmosphere enough oxygen to maintain life.

**The White Corpuscles.**—The white corpuscles are translucent, irregular in shape, and they have more than one nucleus. They resemble the ameba and like it they can move from place to place (Fig. 51). They work

their way through the walls of the blood vessels and escape into the tissues, where they wander about doing valiant service for the body. They are very sensitive chemically. Wherever poisonous substances are present they gather in great numbers and by eating up

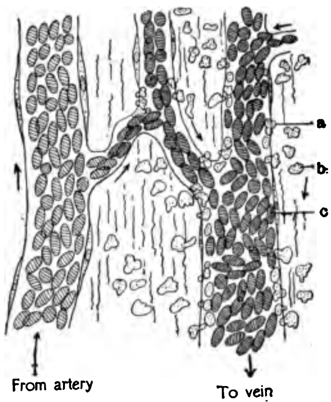



**Fig. 51.—Migration of the white blood corpuscles from the capillaries of a frog into the tissues during inflammation.** ***a*, white corpuscle penetrating wall of capillary; *b*, white corpuscle in tissue; *c*, red corpuscle. (From Fitz, after Warren.)**

microbes and other foreign particles, they are often able to combat successfully severe disease. Matter from festered places is made up largely of these corpuscles.

**Coagulation.**—The white corpuscles are also important because of their influence on the coagulation, or clotting, of blood. They contain an enzyme which has the power to hasten the physical process of coagulation so that it takes place at a much lower temperature than would otherwise be possible.

When the corpuscle comes in contact with any foreign substance like dust or air the enzyme is rendered active.

Through its activity fibrinogen, one of the proteids of the blood, is transformed into fibrin. As the change takes place, the small particles of the proteid which are held in suspension separate themselves from the liquid and assume a fibrous character. The fibers gather together in a larger and larger mass and in so doing enmesh the red corpuscles. These are in no way responsible for the process, for if the blood is whipped with a bunch of wires the fibrin may be obtained quite clear of them.

The power of the blood to coagulate is of great service to the body, because in case of serious injury to a blood vessel, the contraction of its wall tends to close the wound and the coagulation of the blood prevents continued bleeding.

**The Serum.**—When the clot begins to form, the blood changes from a liquid to a red jelly; later the jelly contracts and forces out a yellow liquid. This liquid is the serum. It represents the blood with the fibrin and the red corpuscles removed. Under the influence of heat it also is able to coagulate because of the presence in it of proteids other than fibrin. Out of serum from the blood of horses is made the remedy used so wonderfully in fighting diphtheria.

A glance at the following table will show at once the relation of coagulated blood to the substances present in liquid blood.

| | | | | |
|---|---|---|---|---|
| Coagulated blood | serum | water | plasma | liquid blood |
| | | proteids | | |
| | clot | fibrin | | |
| | | corpuscles | | |

**The Lymph.**—The walls of the capillaries are so thin that not only do the white corpuscles creep through, but by osmosis the plasma, or liquid portion of the blood with its dissolved substances, passes through. This liquid, now called the lymph, is clear and colorless and contains everything in the blood except red corpuscles, which are too large to pass through the capillaries under ordinary conditions. The lymph bathes the tissues and keeps them moist. It brings the dissolved food materials into such close contact with the tissues that they can without difficulty absorb what they need; and through the activity of the white corpuscles, it removes wastes readily.

**The Lymphatics.**—The lymph passes from the capillaries into spaces between the cells. These spaces communicate with each other, and into them open the expanded ends of small tubes, called lymphatics. The small lymphatics unite to form larger and larger tubes until two are formed (Fig. 48). These enter the two large veins near the neck, the larger or left one carrying the fats which were taken up by the lacteals, and pour the lymph into the blood through an opening protected by valves which prevent the backward flow of the blood into the lymphatics. The lymph flows because of the pressure caused by muscular activity. There is no heart or pumping organ connected with the lymphatic system in man; in the frog and certain other lower animals, however, where the lymph spaces are very large, four rhythmically contracting organs called lymph hearts force the lymph onward.

**Vaso-Motor Nerves.**—Contraction and relaxation of

warm; if they are contracted, one feels cold. For this reason if there is little blood in the skin, one may feel cold even when the body is burning with fever.

**Effect of Alcohol on Body Temperature.**—Alcohol prevents the surface blood vessels from responding readily to changes in temperature. A drunken man exposed to great cold is apt to freeze to death, for the relaxed surface blood vessels contain so large a quantity of blood that heat is given off much faster than it is produced. At the same time he may have a pleasureable sensation of warmth because of the unusual amount of blood in the skin.

**Adaptation of the Circulation to Bodily Need.**—Possibly no other system has so many adaptations by which accidental defects correct themselves as the circulatory system. The clotting of the blood and the contraction of the vessels, which, following directly upon an injury, prevent bleeding to death, and the action of the surface blood vessels, which, through heat, are stimulated to cause the body to give off heat, and, through cold, are stimulated to cause the body to conserve its heat, have already been mentioned. In addition, we find that if the heart is stretched by an increased quantity of blood so that a harder beat than usual is necessary to force it out, the stretched muscle is able to beat harder than the unstretched muscle; if continued hard work is demanded, the work itself strengthens the muscle. It grows thicker in response to the demand made upon it and it gains strength to meet the demand. If, however, too great a demand is made, as in the case of some athletes, the heart muscle becomes so thick that it can

not be supplied with nourishment and it loses its power to contract.

The rate of respiration is intimately connected with the rate of circulation, through the action of the vagus nerve, which is connected with both. If the respiration becomes slower and deeper, the heart beat becomes correspondingly quicker, so that the blood is kept moving fast enough to get sufficient oxygen for the body.

If the pressure in the large arteries is lessened by the dilation of the smaller ones, the heart again works more quickly, blood is pushed faster into the large arteries, and the pressure is kept great enough to supply the tissues with blood.

If the heart beats too fast, the extra pressure stimulates the depressor nerve and the beat is immediately decreased.

**Summary.**—The blood is the great carrier of the body. It transports oxygen and digested food products to tissues deficient in them, and it carries the waste products of oxidation from the tissues to the excretory organs. It is a salt solution containing in suspension proteids and living corpuscles. The red corpuscles are important because they act as a storehouse for oxygen, and the white corpuscles are important because they help the body to resist disease and because they assist the clotting of the blood.

The passage of the blood through the body is determined by five mechanical features. The heart through its rhythmical beat furnishes the motive power. The valves force the blood to go in one direction only. The tubes to which the blood is confined are so arranged that

the blood is forced to return to the heart after its passage through the body. The elastic walls of the arteries stretch to receive the blood and by pressing upon it force it to go onward in a steady stream. The tone, or the sustained activity of the muscles in the walls of the small arteries, regulates the capacity of the entire system, so that the tubes are always full of blood; it controls the amount of blood going to the tissues so that they always get the supply of oxygen and food that they need; and it keeps the body temperature constant.

## CHAPTER V

## REPRODUCTION

**Origin of Living Matter Unexplained.**—Through a long series of slow changes the earth as it exists to-day was developed from a kind of nebula, and complex organisms that live upon the earth were evolved from very simple organisms. We do not understand how the nebula or non-living matter first came into existence, and we do not understand where and how the first living form originated. It seems but a step from non-living matter to the simplest form of living matter, yet it is a step that marks a sharp distinction and we do not know how it was taken. Some day perhaps we may bridge the gap in our knowledge and find out how the peculiar combination of non-living elements called protoplasm became endowed with life, but to-day we must content ourselves with the knowledge that the subtle thing that we call life transfigures the mass of elements and gives it a threefold power to move, to grow, and to reproduce, and so distinguishes it absolutely from all forms of non-living matter.

**Reproduction.**—Living matter is able to manufacture new substances like itself from food that it assimilates. Living organisms in consequence grow and when they reach maturity they produce out of the extra protoplasm

that they make new organisms like themselves. This power is called reproduction. It belongs to all organisms alike. In one-celled animals the process is of course very simple, but it does not differ very widely in its essentials from the process as it exists in higher animals.

**In One-Celled Animals.**—The simplest form of the process is called fission. A one-celled organism splits

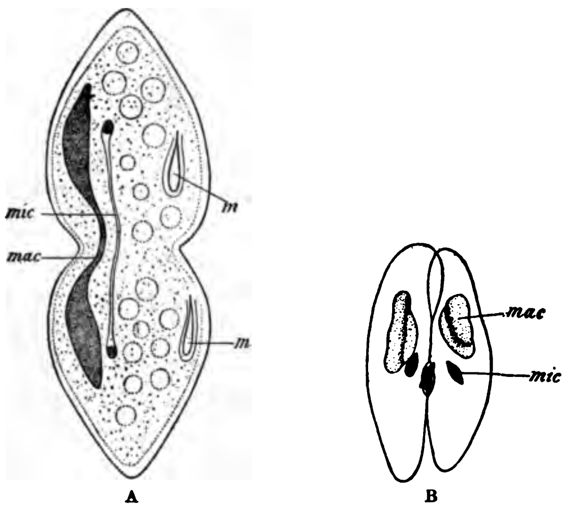



FIG. 52.—Paramecium. *A*, Fission; *B*, Conjugation. (From Sedgwick and Wilson, after Calkins.) *m*, mouth; *mac*, *mic*, nucleus.

into two and in place of the single individual there are two half-sized individuals. These grow and the process is repeated. After a time the animals seem to lose their vigor and are unable to divide unless the protoplasm is rejuvenated. This is accomplished through a process called conjugation. Two animals apparently alike come

close together and the protoplasm, or the nucleus, of the one passes into the protoplasm of the other. The fusion that follows gives the cells an increased impetus toward division and the necessary strength for it (Fig. 52).

**In Many-Celled Animals.**—Conjugation is not unlike the process of fertilization that occurs in human beings and other many-celled animals. In this process two dissimilar cells unite, and the union results in the formation of a new cell with the power to divide and form other cells. In many-celled animals the cells do not split entirely apart when they divide but remain attached to each other. Soon they become differentiated, that is they grow different in form and function, and finally an animal like the parent is formed. Complete separation, however, occurs in certain worms where an animal may split into two new animals, and also in those organisms which are able to form a new individual from a bud or cut off portion.

**Restricted to Special Cells.**—In one-celled organisms any cell may by fission produce a new organism like the parent. In many-celled organisms any cell may divide, but the power to form a new individual like the parent is restricted to certain undifferentiated cells called the reproductive cells. This is necessarily true, for when a cell divides after differentiation the new cell is differentiated in the same way; but if a simple undifferentiated cell divides, the new cells retain the power of differentiation and are able to give rise to the various tissues of the new organism.

**Reproductive Cells of the Sea-Urchin.**—Reproduction in a many-celled animal like the sea-urchin is very

simple. These animals live in the water (Fig. 53). At certain seasons of the year primitive, or undifferenti-

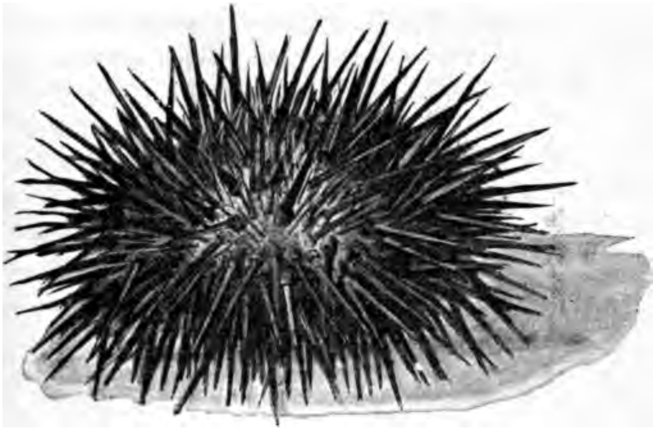


FIG. 53 A.—Sea-urchin.

ated, cells multiply in their bodies in great numbers. These cells are formed by special reproductive organs

FIG. 53 B.—Sea-urchin with spines removed.

which open to the outside by a tube or duct. The organs are of two kinds and are found in different individuals

called the male and the female. They give rise to cells, which differ from each other very definitely. Those formed in the female are large, round and have no power of themselves to move. They are called egg cells, or ova. The organ in which they are formed is the ovary. In the male the cells are small, irregularly shaped and motile (Fig. 54). They are called spermatozoa, or sperm cells, and the organ in which they are formed is the spermary.

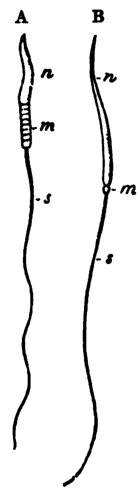



FIG. 54.—Spermatozoa. *A*, of the nighthawk; *B*, of the green frog; *n*, nucleus; *m*, middle piece; *s*, tail. (After Hertwig.)

**Attraction of the Sexual Cells.**—The egg cells have a chemical attraction for the sperm cells. By vibrating the long tail-like appendage, the sperm cells move through the water and approach the egg cells. One of them punctures the wall of an egg cell, and its nucleus, with the slight amount of protoplasm surrounding it, enters. The tail is left outside and finally disintegrates. A single cell then remains, containing two nuclei, one belonging to itself, the other to a cell of different character. These nuclei fuse. The large cell with now but a single nucleus has, like the one-celled animal after conjugation, a new and increased power of division.

**Division of the Fertilized Egg.**—It divides very rapidly first into two cells, which remain attached to each other, then into four, eight, sixteen, thirty-two cells and so on, until a mass like a mulberry is formed

(Fig. 55). All of these cells have a marked affinity for oxygen. Those on the inside therefore push their way

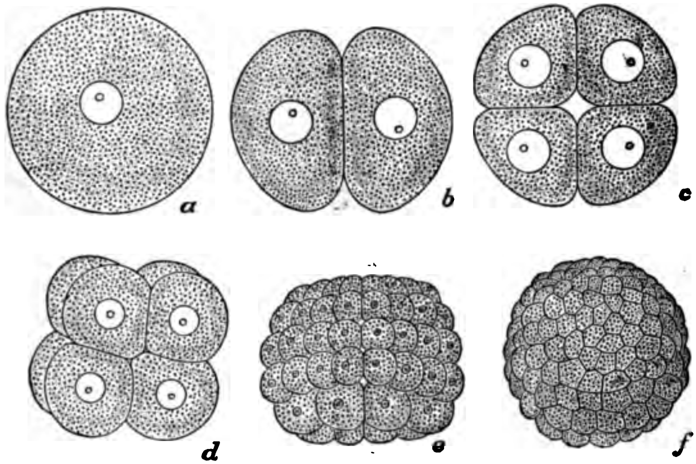



FIG. 55.—*a*, egg cell; *b,c,d,e,f*, successive stages of division. (From Sedgwick and Wilson.)

to the outside toward the oxygen. In this way they become arranged in a hollow sphere called a blastula (Fig. 56). As these cells have their affinity for oxygen satisfied, some of them develop a new affinity. They are attracted toward other cells and move inward until a pear-shaped structure called a gastrula (Fig. 57) is formed, which has a wall composed of two layers of cells and an opening leading from the central cavity to the outside.

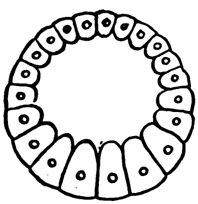


FIG. 56.—Diagram of a blastula.

**Differentiation of Cells.**—The two layers of cells are

now exposed to very different conditions; in consequence they assume different characteristics. The cells in the outer layer, in contact with sea water, become more or

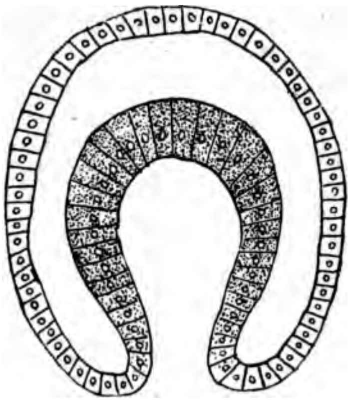


FIG. 57.—Diagram of a gastrula.

less hardened and assume a protective function. Those on the inside assume a nutritive function. We thus have formed two primitive layers called the *ectoderm* and the *entoderm.* As the cells increase in number a new layer called the *mesoderm* is formed between them. These are the three primary layers. From them all the tissues of the adult organism are formed. The higher the animal the more marked the power of cellular differentiation, and the more highly developed the resulting tissues. From the ectoderm all protective organs are formed, skin, nervous system, sense organs; out of the entoderm, all organs which have to do with alimentation, the alimentary canal, the liver, pancreas, lungs;

out of the mesoderm, everything else,—bones, muscles, blood, connective tissue, glands.

**The Process Universal.**—The development of the sea-urchin up to the gastrula is typical. The main changes that have been described as taking place during fertilization, cleavage of the egg, and formation of the first two germ layers occur in all multi-cellular animals. Each particular group of animals, however, has its own peculiarities of development resulting from variations in environment or structure. Some animals like the hydra never pass beyond the gastrula stage. Others more highly developed pass through all of the stages of their immediate ancestry. In other words, "the history of the individual repeats the history of the race." This fact is one of the strongest arguments in favor of the theory of evolution; it seems to justify the assumption of a common ancestry, and belief in the evolution of complex from simple forms.

**Protection of the Cells in Land Animals.**—In land animals egg cells and spermatozoa can not be turned loose because their delicate outer walls would dry in the air and the cells would die. Some way must therefore exist by which the sperm cell may reach the egg cell without danger of the death of either one. The cells reach the exterior of the sea-urchin through tubes that lead from the organs where the cells are formed to the outside. These tubes are moist. In land animals the cells come in contact with each other without exposure to the air in one of the tubes.

As the egg cell can not move and the sperm cell can move, the sperm cell passes over to the tube containing

the egg cell. The two unite in the tube and the egg gains the power of division and differentiation. In insects, birds, reptiles, after the process of fertilization occurs, a hard outer wall forms around the eggs. They can then be exposed to the air without injury. The process of differentiation and growth continues within the shell until the young animal can take care of itself, when it is hatched. In higher animals, where a hard shell does not form, the egg can not be exposed to the air until it is so protected that no harm will result. Therefore, the length of time that the fertilized egg remains in the tube and the amount of development which takes place there depend upon the degree of development which is necessary for the protection of the new individual. In the case of human beings the new individual must be completely formed before it leaves the tube.

**Sexual Reproduction of Plants.**—In plants the process is essentially the same. The ultimate end and aim of all organisms seems to be the reproduction of their own kind; the flower is not made to please our eyes but to aid in the production of a new plant. The brightly colored floral envelopes usually present surround the more important stamens and pistils (Fig. 58). These may, or may not, appear in the same flower. The pistil is a tube (the style), with a basal enlargement (the ovary) and a flaring end (the stigma). In the ovary, as the name indicates, the ovules, or egg cells, are formed. Each of these may be compared to a female sea-urchin, for it forms within itself a little egg cell which must be fertilized if it is to develop into a new individual.

The stamen is a long filament with an anther at the top. The anther gives rise to the pollen grains. These grains are so tiny that they are easily blown about by the wind

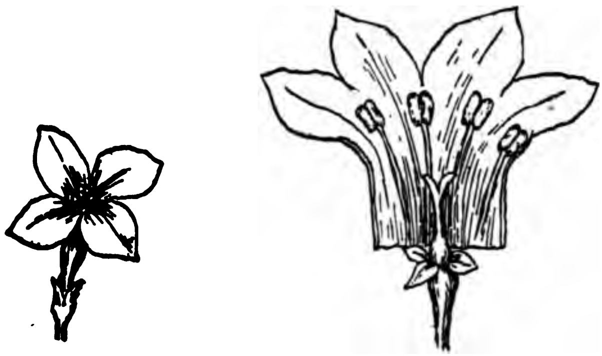


FIG. 58.—Flower showing stamens and pistil.

to fall perhaps on the sticky surface of the stigma. Each little pollen grain may be compared to the male sea-urchin, for it forms within itself a sperm cell.

The sperm cell, like that of the sea-urchin, is irregularly shaped and develops a tail. The tail is of no use for swimming because it is not surrounded by water and it is held fast by the sticky surface of the stigma; but by means of it the nucleus of the sperm cell reaches the egg cell. The tail, or pollen tube, grows longer and longer until it reaches down the style to the ovary; the nucleus of the cell then works its way down through the tube, punctures and enters the egg cell and unites with the nucleus which it finds there (Fig. 59). This is the process of fertilization. The new cell, like the fertilized

egg of the sea urchin, can now divide and the new cells can differentiate. The process of differentiation continues until a tiny new plant called a seed is formed.

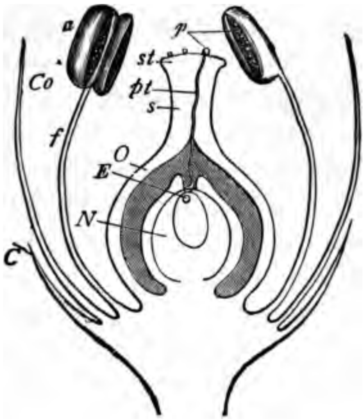



FIG. 59.—Diagrammatic section of a flower, showing a pollen grain sending a pollen tube down to the ovule. *C*, calyx; *Co*, corolla; *a*, anther, and *f*, filament, of the stamen; *O*, ovary surmounted by *s*, style, and *st*, stigma; *p*, pollen grains, some in the anther, others on the stigma; *N*, ovule; *E*, germ cell; *pt*, pollen tube penetrating the style and reaching the germ cell through an opening (the micropyle) into the ovule.

Under proper conditions this is able to unfold itself into a plant like the parent.

**Summary.**—Reproduction may be non-sexual or sexual. In non-sexual reproduction a cell, or a collection of cells, breaks away from the parent and develops into a new organism. There is no union of cells. In sexual reproduction two cells unite to form a new cell which has the power to divide and differentiate. In one-celled forms the uniting cells are similar and we call the process conjugation. In higher forms the cells are

dissimilar and we call the process fertilization. The two cells are usually formed in different individuals, though they may be formed in the same individual. The egg cell is large, round, quiet; the sperm cell is small, irregular, motile. In aquatic forms the cells pass into the water and unite there, but in animals that live on land the union takes place in the tube leading from the ovary to the outside. The egg becomes better and better protected as development becomes more complex; finally it remains in the body until the whole development has taken place.

## CHAPTER VI

## IRRITABILITY

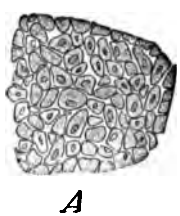
**Protoplasmic Motion.**—Living matter is irritable; that is, it has the power to move in response to a stimulus. The character of the motion varies. Sometimes the protoplasm circulates within the cell. This flowing movement aids in the distribution of nutritive substances to all parts of the cell and in the concentration of wastes. It may also bring about the movement of the cell from place to place. The ameba and the white blood corpuscles, for example, creep slowly along in the direction in which the protoplasm flows (Figs. 16, 50 B).

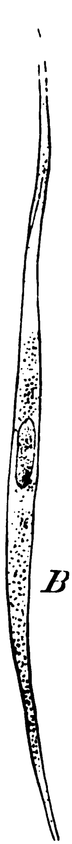
**Ciliary Motion.**—Sometimes the cells have hair-like projections from their surface which move to and fro. By the concerted movement of these cilia a free cell easily moves from place to place like a boat propelled by oars (Fig. 2). If the ciliated cells form the surface of a membrane like that covering the gills, or lining the œsophagus, of many animals, the moving of the cilia produces a current which, passing over the surface of the membrane, carries along any substances contained in the liquid that bathes it.

**Muscular Contraction.**—In many-celled animals some cells have been so differentiated that they are able to change their form by contracting and relaxing. These

are called muscle cells (Fig. 60). They are usually long and slender and they are arranged in groups in such a way that when they contract, the group, or the muscle as a whole, contracts (Fig. 61). As each cell grows shorter and thicker, the muscle grows correspondingly shorter and thicker and the effort of the individual cell is magnified. Through the activity of these cells an animal is able to change its form and move from place to place.

**Theory of Muscular Contraction.** — Various theories have been advanced to explain how a muscle cell contracts but they are not satisfactory. With the aid of a compound microscope, certain definite changes may be seen to take place in the structure of the cells during contraction. These may be accounted for by the



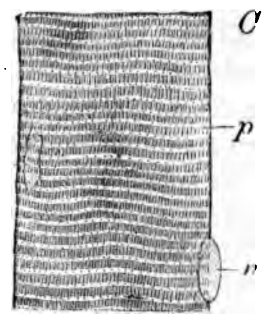




FIG. 60.—Muscle cells. *A*, cross section from intestine of a dog; *B*, isolated cell from intestine of a rabbit; *C*, part of a single fiber of voluntary muscle from the leg of a rabbit; *p*, protoplasm; *n*, nucleus. (From Sedgwick and Wilson, after Ranvier.)

theory that when protoplasm disintegrates, as it always does during activity, the resulting heat causes the pas-

sage of a fluid from one part of the cell to another part so that its shape is changed. This would be a satisfactory explanation were it not for the fact that an appreciable time is necessary for the passage of the fluid, and the muscles in the wings of insects move far too fast to permit it to occur.

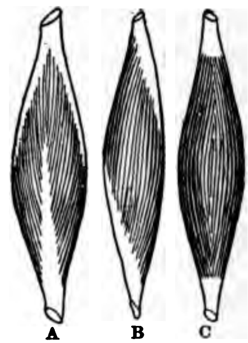



FIG. 61.—Diagram showing arrangement of muscle fibers in relation to their tendons. *A*, in muscles contracting through a considerable distance; *B*, in muscles of shorter and more powerful contraction; *C*, in muscles of very short and powerful contraction. (From Fitz.)

**Stimuli.**—A muscle contracts in response to some outside stimulus. This stimulus may be physical, e.g. a blow, or a change of temperature; or chemical, e.g. an acid or other irritating substance. Some muscles seem to work automatically without the intervention of an outside stimulus, but their spontaneity is only apparent. They are really stimulated by some substance present in the blood. The heart is probably the most remarkable of these muscles, for it contracts rhythmically as long as there is life, and so long as it is provided with adequate nourishment it seems to thrive under the constant work.

**Rhythmical Contraction.**—Muscles which normally do not show rhythmical contraction will contract rhythmically if excised and placed in a balanced solution of sodium chloride and calcium chloride. These salts are present in the blood in such proportion that the blood is the balanced solution for the heart muscle. So long

as it is bathed by the blood then, and its chemical constitution remains unchanged, the heart will continue its contractions indefinitely.

The excess of carbon dioxide that occurs at regular intervals in the blood is possibly the stimulus which incites the respiratory muscles to rhythmical activity.

The movement of the muscles in the wall of the alimentary canal by which the contents of the canal are continually urged onward is also apparently spontaneous, but the presence of any foreign substance in the intestines stimulates its muscular walls to activity. The presence of the food then is an exciting cause.

**Influence of the Structure of Muscles.**—The important thing about the muscles is that through their contraction they bring about the complex movements of higher organisms. Each muscle is capable of a single movement. It changes its shape in accordance with the arrangement of its fibers, or cells, which grow shorter during contraction. In the muscle that bends the arm, the fibers lie side by side so that when they contract the muscle grows shorter, but in the diaphragm they are the radii of a circle and when they contract the circle grows smaller.

**Influence of Arrangement of Muscles.**—Complex movements are produced by the co-operative activity of a number of muscles. The character of the movement depends upon the shape and the arrangement of the muscles in the body of the animal. In an earthworm one set of muscles runs lengthwise and another encircles the animal. By the alternate contraction of the two sets the worm creeps over the ground. In a sea anemone the

body is cylindrical and the muscles run lengthwise. When they contract they pull the animal back against the rock to which it is attached.

The number, shape and arrangement of muscles vary greatly in different animals. In simple animals they are few in number, they are arranged very simply, and few movements are possible. In higher animals they are numerous and they vary greatly in size, shape and arrangement. An infinite variety of movements may therefore be produced by their contraction.

**The Function of a Skeleton.**—Very simple animals are more or less jelly-like and formless. In larger and more complex animals the soft tissue is supported in order that the shape of the body may be maintained and the necessary resistance furnished for complex movements. The food that they eat contains earthy matter which is built in the body into a strong resistant substance firm enough to form a support. The softer parts of the body thus become protected by the development of a skeleton.

**The Skeleton External in Lower Animals.**—In lower animals the skeleton is on the outside of the body, but it must not be regarded as a house which the animal enters or leaves as it likes. It is an integral part of the animal. In oysters and clams the body lies inside a shell made of two pieces which may be opened or closed by the activity of strong muscles attached to it. In starfish, lobsters and insects the connection is closer. The enclosing shell is jointed and the muscles are so intimately connected with it that every movement involves a movement of the shell.

**Internal in Higher Animals.**—In higher animals the skeleton is internal. It is entirely covered by muscles and its bones are so arranged that they move easily when the muscles associated with them contract. There are in man a great many bones (208) of varied shape and size, usually described as long, short, flat or irregular. Except in the head, the hip, and the lower part of the spine where the bones are fused or sutured, a joint permitting more or less motion is formed wherever two bones come together. The separate bones at the joint are held in place by strong ligaments of fibrous, inelastic tissue. They slip over each other easily and smoothly because the surfaces that come in contact are covered with smooth cartilage that is constantly kept moist with fluid.

**The Structure of Bones.**—The bones are composed of living animal matter, water, and earthy matter mostly salts of lime. They are rigid, strong and light. The large bones attain the necessary size without too much weight by becoming hollow or by developing spongy bone inside. The number, the shape of the bones, the wonderful way in which they are fitted together, their strength and lightness insure the ease and quickness with which we are able to move.

**The Spinal Column.**—The fundamental part of the human skeleton is the spinal column, or backbone, which is so constructed that it combines the greatest strength with the greatest flexibility. The separate bones of which it is composed may be felt through the skin. They vary in form according to their situation, and in consequence they vary in the amount of motion that they are able to make. In the neck, for example, there is

much more freedom than there is in the trunk. Movement between any two vertebræ is restricted by the uniting ligaments, but there are so many vertebræ that though each one moves but slightly, the column as a whole is capable of bending considerably (Fig. 62).

**The Shoulder Girdle.**—About the spinal column as an axis the other bones are arranged so that the body has a two-sided symmetry. It is surmounted by the head and to it are attached two bony girdles each of which carries a set of appendages (Fig. 63). The shoulder girdle consists of two shoulder blades which lie one on each side of the back, two collar bones which lie at the base of the neck in front, and the breast bone to which the collar bones are attached. The upper end of the arm bone fits into a shallow cup at the upper outer end of the shoulder blade.

**The Pelvic Girdle.**—The pelvic girdle consists of two broad flaring bones joined together by ligaments in front and united to the spine by ligaments in the back. The upper end of the leg bones fits into a hollow.

FIG. 62.—Side view of the spinal column. (From Martin.)

**The Ribs.**—The ribs encircle the body and enclose

the heart and lungs. They are united to the vertebræ behind and to the breast bone in front and furnish sup-

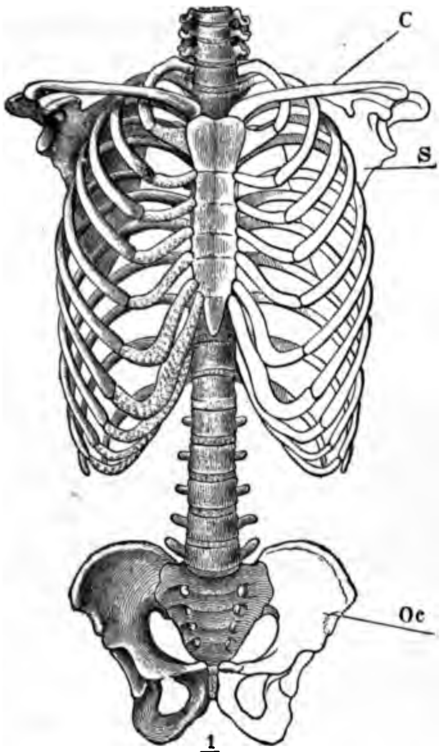



**Fig. 63.—The skeleton of the trunk seen from the front, showing the shoulder girdle composed of the collar bone (*C*) and the scapula (*S*), and the pelvic girdle composed of the sacrum and the innominate bones (*Oc*). (From Martin.)**

port for the shoulder girdle and the arm muscles. As they are not rigidly fastened they are capable of movement which aids breathing (Fig. 64).

**Appendages.**—The legs and arms are each divided

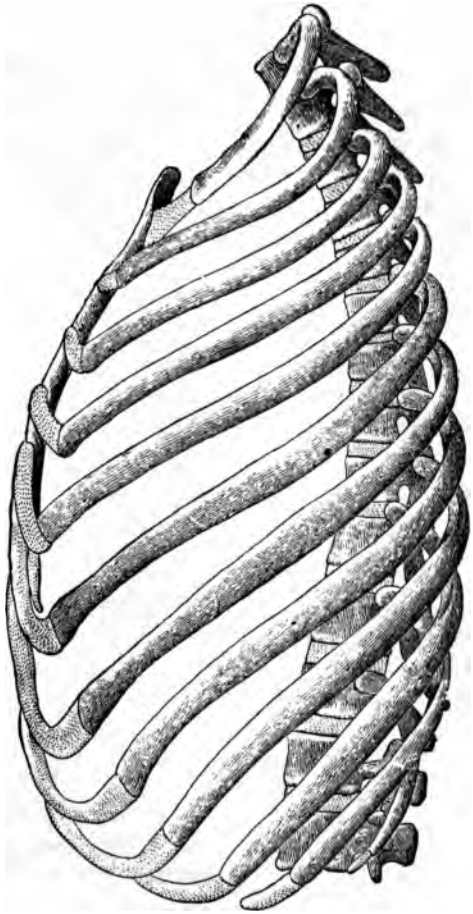


FIG. 64.—The ribs of the left side, with the dorsal and two lumbar vertebræ, the rib cartilages and the sternum. (From Martin.)

into an upper part, consisting of a single large bone, and a lower part, consisting of two bones placed side by side that turn on each other. A number of small bones con-

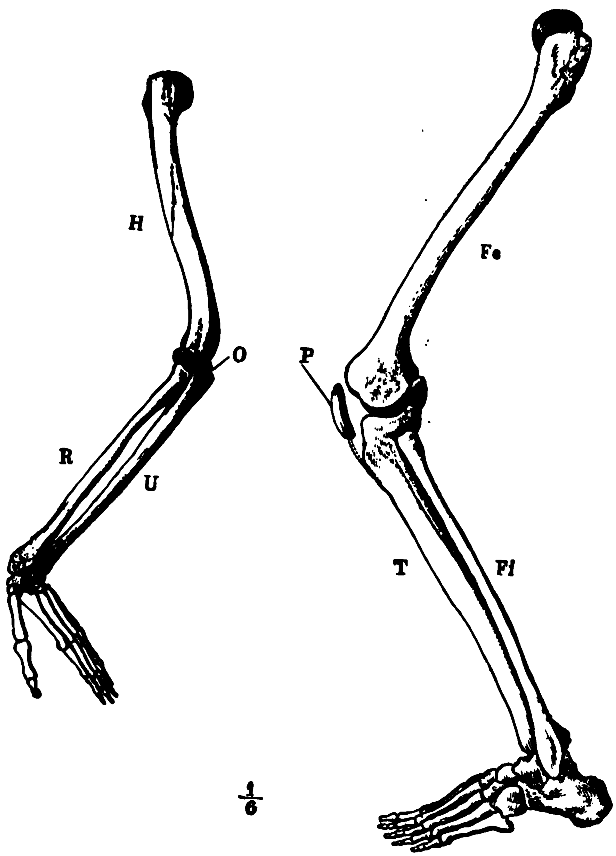



FIG. 65.—Bones of arm and leg. *Fe*, femur; *Fl*, fibula; *H*, humerus; *P*, patella; *R*, radius; *T*, tibia; *U*, ulna. (From Martin.)

nect these with the bones of the hand and foot, which are each made of five slender bones. The first of these five is tipped with two small bones and the others

each with three small bones, for the fingers and toes (Fig. 65).

**Joints.**—Wherever two bones come together to form a joint, the one nearest the center of the body acts as a support for the motion of the other one. At the shoulder, for example, the upper arm moves, the shoulder remains quiet; at the elbow the lower arm moves, the

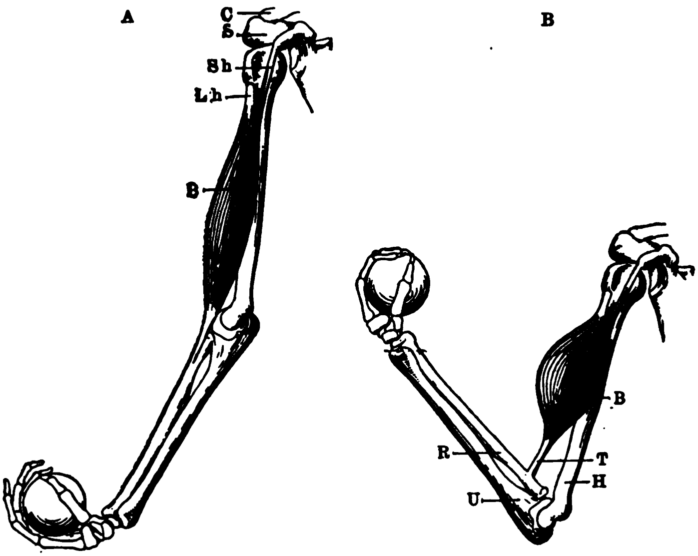



**Fig. 66.**—*A*, lengthening of biceps when arm is extended; *C*, clavicle; *S*, scapula; *Sh*, short head of biceps; *Lh*, long head; *B*, biceps. (From Fitz.) *B*, contraction of biceps to flex arm; *S*, scapula; *B*, biceps; *T*, tendon; *H*, humerus; *U*, ulna; *R*, radius. (From Fitz.)

upper arm is quiet; at the wrist the hand moves, the lower arm is quiet. There is an advantage in this, for it insures quickness and ease of movement for the extremities.

**Relation of Muscles to Bones.**—Bones have no power of themselves to move. Their movement is entirely due to the contraction of muscles that are attached to them (Fig. 66). An infinite variety of movement is possible through the co-ordinated activity of a great number of muscles. These vary greatly in shape and size and are arranged about the skeleton in such a way that the beautiful symmetry of the body is maintained and the greatest amount of work accomplished with the least expenditure of energy.

If we feel the muscles through the skin when they contract we may notice that the active muscle is frequently situated some distance from the point of motion. The muscles that move the upper arm are situated on the trunk, those that move the lower arm are situated on the upper arm and those that move the fingers are situated close to the elbow. The weight of the muscle thus rests on the stationary bone and the other bone is free to move. The muscles are fastened to the bones by inelastic tendons that are sometimes very long. The tendons economize space and slip easily over the moving joint.

The muscles are arranged about a joint so that its motion is perfectly controlled; the number depends upon the character of the joint and the character of its work. In the shoulder where a ball and socket permit rotary motion there are a large number of muscles, but in hinge joints which merely permit flexion and extension, only two controlling muscles are necessary though in powerful action these may be reinforced by others.

Movement is always due to contraction, not to relaxation. Usually muscles are arranged in antagonistic pairs

so associated that if one contracts the other relaxes. On each side of a hinge joint is a muscle attached to both bones; one bends the joint when it contracts, the other straightens the joint when it contracts. In moving the eye to the right, the outside muscle of the right eye contracts while the inside muscle relaxes (Fig. 67). At

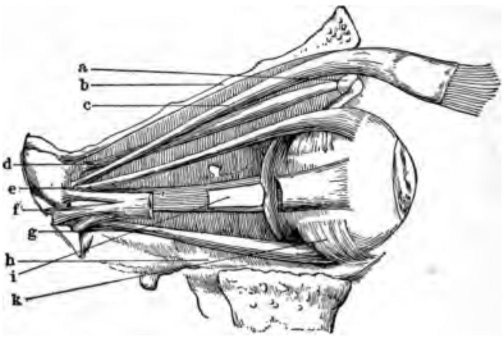



FIG. 67.—The eye and its muscles. *a*, pulley of upper rotating muscle; *b*, part of skull (eye socket); *c*, muscle of upper lid; *d*, upper rotating muscle; *e*, muscle turning eye upward; *f*, muscle turning eye outward; *g*, muscle turning eye downward; *h*, bone of socket; *i*, optic nerve; *k*, lower rotating muscle. (From Fitz.)

the same time, the inside muscle of the left eye contracts while the outside muscle relaxes. Both eyes thus move together.

**Relation of Nerves to Muscles.**—If the finger touches a hot stove, the muscle that jerks it away is likely to be one of those in the upper arm. This muscle did not come in contact with the stove, yet the stimulus reached it. There must therefore be a passageway by which a stimulus applied to the skin can reach a muscle far removed from the point of contact. This connecting passageway is furnished by the nerves.

**Structure of the Nervous System.**—A nerve is made of fibers that are prolongations of large irregular cells (Fig. 68). Like the circulatory system, the arrangement of the nerves depends on the shape, size and development of the animal. In the starfish, for example (Fig. 69), it is star-shaped, for a ring around the mouth sends a branch to each ray.

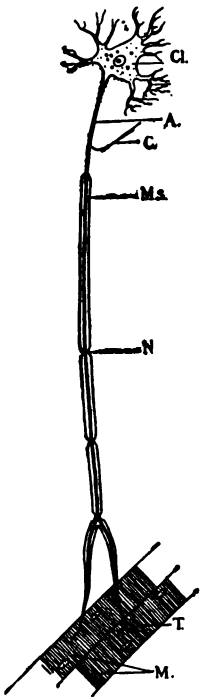


Fig. 68.—Diagram of a motor nerve cell. *Cl.*, motor nerve cell of spinal cord; *A.*, axis cylinder; *C.*, collateral branch; *Ms.*, medullary sheath; *N.*, node; *T.*, terminal branches; *M.*, muscle. (From Fitz.)

There are always one or more central masses of cells from which the fibers radiate. In worms and lobsters these masses of cells are arranged at intervals along a cord that extends the entire length of the body (Fig. 70). This is the prototype of the spinal cord of human beings. The spinal cord is the fundamental part of the vertebrate nervous system. It is situated in a canal formed by the vertebræ where it is thoroughly protected. From this cord nerves are given off at regular intervals. These subdivide into smaller and smaller nerves which go to every part of the body. At the anterior, or head end, of the cord the cells are massed into a large organ called the brain which also gives off nerves in the same way. These go to

the face and the various parts of the sense organs (Fig. 71.)

**The Work of Nerves.**—The nerves form the only protoplasmic connection between the skin and various

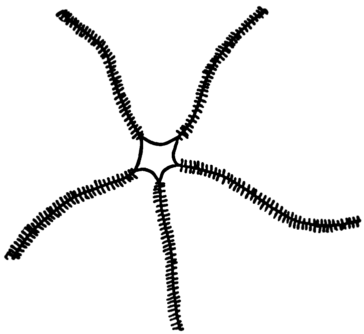


FIG. 69.—Diagram of the nervous system of a starfish

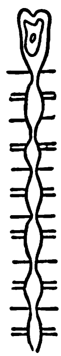


FIG. 70.—Diagram of the nervous system of an earthworm.

muscles. When a nerve ending in the skin is stimulated by some form of physical or chemical contact, the stimulus passes down the nerve and gives rise to a sensation, or to the contraction of a muscle, or to both. A sensory nerve carries a stimulus to the ventral or front side of the spinal cord. From there it may pass through the spinal cord to the brain and give rise to a sensation; and it may also pass to the dorsal side of the spinal cord and back to the muscles through a motor nerve and give rise to a contraction. Sometimes the passage is so quick from the point of contact to the muscle that the stimulus does not have time to go to the brain first. The movement then takes place before the mind knows anything

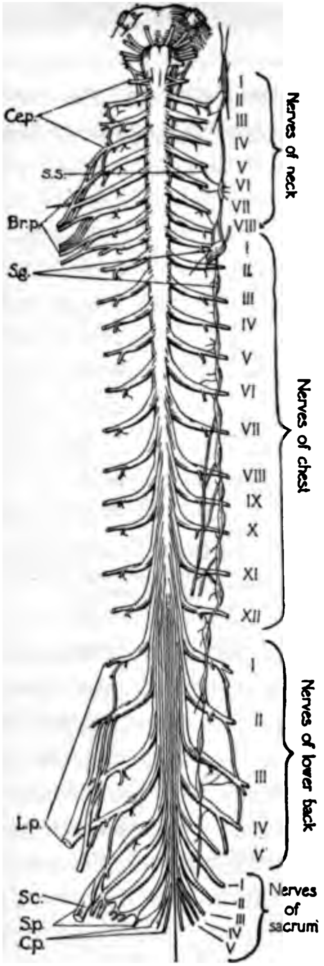



FIG. 71.—Diagrammatic front view of the spinal cord and bulb, showing spinal nerves, one side chain of sympathetic ganglia, and some of cranial nerves. *Ce.p.*, cervical plexus; *s.s.*, branch to sympathetic system; *Br.p.*, brachial plexus; *S.g.*, sympathetic ganglia; *L.p.*, lumbar plexus; *S.c.*, sciatic nerve; *S.p.*, sacral plexus; *C.p.*, coccygeal plexus. (From Fitz.)

about it. We can neither aid nor interfere with it. This is called a reflex movement.

**The Value of the Nerves.**—The value of the nerves to the body lies in their extreme sensitiveness and in the rapidity with which a stimulus passes through them. Many experiments have been tried with lower animals to ascertain whether nerves are responsible for their various reactions or whether the reactions are dependent upon muscles. By removing the nerves from these animals so that they can play no possible part and by stimulating the muscles directly, it was found in every case that the animal showed its usual reaction and that this reaction depended

upon the structure and arrangement of the muscles. But it was always found that the reaction was very, very slow in following the stimulation. This means that if the animal had to depend on the direct stimulation of the muscle its life would be in danger because the reaction could not come quickly enough. When animals as highly developed as dogs are deprived of the use of the nerves, they are kept alive with a great deal of difficulty because of the slowness with which the body responds to changes in temperature.

These experiments show that human beings are utterly dependent upon the nervous system, for without the nerves the muscles would respond to stimulation too slowly to maintain life. But while we recognize the importance of the nerves we must realize wherein it lies. They are in no sense responsible for movements. This is the work of the muscles. They cannot initiate a movement. This is the result of a stimulus. But they are extremely sensitive and they conduct a stimulus with wonderful rapidity. They are therefore effective as conductors of stimuli.

**Sense Organs.**—All nerves are sensitive to chemical and physical stimuli, but nerves connected with the special senses are especially adapted to particular stimuli. The most widely distributed of the senses is that of touch, or sensitiveness to physical contact with external objects. It is found in all animals and it is generally distributed over the whole body. The other senses are restricted to special areas on the body and, in their complete development, to higher animals. The taste nerves are stimulated by substances in solution,

and the olfactory nerves by volatile substances. The one is distributed over the tongue in higher animals and the other over the upper part of the nose cavity. To what extent the lower animals possess these senses is a question. They can certainly distinguish substances that please them for food and they frequently make their way unerringly to food from a distance, but it is not probable that they smell and taste consciously as we do.

The nerves stimulated by vibrations are perhaps the most sensitive of all. The optic nerve which is responsible for sight is stimulated by ether vibrations; the auditory nerve by means of which we hear, by air vibrations. Some of the lower animals have rudimentary organs sensitive to sound and light but they have no eyes that can distinguish form as do ours and no ears that hear as do ours. The human eye is marvelously developed. Like a photographer's camera it reproduces an image on the sensitive surface of the retina and the impression of form and color is conveyed to the brain by the optic nerve.

**Sympathetic System.**—Many of the spinal nerves are connected with a chain of ganglia which lie in two rows on the ventral side of the spinal column. The ganglia and the nerves that are given off from them form what is called the sympathetic nervous system (Fig. 71). It is so called because it is extremely sensitive to the condition of the body. Through it the organs are adjusted automatically to their needs and to the demands made upon them. If food is present in the stomach its glands are stimulated to activity. If the blood pressure falls the

heart is stimulated to beat faster, if it rises, to beat more slowly. If a muscle is active the blood vessels that go to it are stimulated. They enlarge and carry more blood to it. After violent exercise when a great deal of heat has been set free by the activity of the muscles the surface blood vessels in the skin are stimulated and they enlarge. Also the sweat glands are stimulated to activity and an increase in perspiration follows. If the skin loses heat through sudden or prolonged constriction of the surface blood vessels one is apt to feel cold and shiver. Shivering is a spasmodic contraction of the muscles. The heat thus produced compensates for that which has been lost and tends to produce a feeling of warmth.

**Exercise.**—Exercise is an important factor in the health of the body. It is a natural form of massage. It involves the disintegration and reformation of protoplasm, the kneading of the blood vessels, a quicker heart action and deeper respiration. Thus it facilitates the intake of oxygen and the carrying off of waste products. It must, however, be of the proper sort and must be taken in moderation, and with due regard for times and seasons. Exercise should not be taken too soon after eating because the blood circulates rapidly through the exercised parts, the blood vessels there become enlarged and draw blood away from the stomach where it is due at that time.

Curiously enough either too much exercise or too little has exactly the same effect—a lack of oxidation. In both cases disintegration of complex substances in the muscle takes place in excess and oxygen is

not supplied fast enough to oxidize the resulting products.

If too much exercise is taken habitually as often happens in the case of athletes, the effects may be disastrous. When a muscle is properly exercised it increases in size, if it is well nourished and well aërated it becomes stronger and better able to work. This is true of the heart as of every other muscle.

The blood that passes through the heart at every beat does not come intimately enough in contact with the tissue of the heart to furnish the necessary nourishment. This is brought by the coronary artery which permeates its tissue. If too great demand is made on the heart, the heart muscle becomes so thickened that the coronary artery can not supply sufficient nourishment, the muscle then degenerates and loses the power to contract.

The development of the athlete is not always towards perfection. Where one set of muscles is used to the exclusion of another set, the first becomes over-developed at the expense of the latter. The result is the very disagreeable condition that is called muscle-bound.

**Effect of Alcohol on the Nervous System.**—Indulgence in alcoholic drinks has a decidedly deleterious effect on the nervous system.

Alcohol apparently stimulates the body and mind to greater activity and it is taken frequently for its exhilarating effect. In reality instead of stimulating the brain to work more clearly it acts like a narcotic and inhibits the activity of the restraining influences of the will and of habit. This inhibition results at first

in a throwing off of conventionality so that a person may do things which in a normal moment seem impossible because of the influence of habit. If larger quantities are taken, all strength is inhibited and we find the peculiar vagaries of the drunken man. Control of mind and body is lost; speech becomes thick and unintelligible; muscular action becomes loose and ineffective; and in addition to the loss of voluntary control, involuntary physical control is lost.

Alcoholic indulgence is particularly bad for young people because it stunts growth and because the danger of forming the habit is infinitely greater before the age of thirty than it is afterwards.

**Summary.**—Irritability manifests itself in the circulation of protoplasm within the cell, in ciliary motion, and in muscular activity. In higher animals the movements of the body are due to muscular contraction. The contraction takes place in response to an outside stimulus, either physical or chemical, which is conveyed to the muscle through a nerve that is very sensitive and able to convey stimuli quickly and easily.

The variety of movements that we are capable of making is due to the number, shape and arrangement of muscles and their relation to the bones. The bones are so arranged that they maintain the shape of the body and act as levers to aid the motion.

Neither nerves nor bones can initiate a motion. The muscles are responsible.

Muscular activity is important because it is intimately connected with every function of the body. During activity, disintegration of complex substances in the

muscle and the oxidation of resulting products, occur. From unstable compounds, stable compounds are formed. These stable compounds are no longer of use to the bodily machine so they are given off as wastes through the excretory organs. The chemical actions involved set free an enormous amount of heat which is distributed through the body, or given off from its surface. The disappearance of complex substances creates a demand for food and oxygen which are brought to the muscle through the quickening of the circulation and respiration, and used for the manufacture of new complex substances.

# PART II

# INTRODUCTION

In the second half of this book the great groups of animals will be considered in order to show how the functions are affected by structural development. Descriptive details which have already been presented many times fully and delightfully will be reiterated only in so far as may be necessary to emphasize the fact that the life processes in living organisms continue in direct response to an involuntary conformity to natural laws.

Each science has its own body of well-established laws, yet year by year the limits of the sciences become more and more vague, and their laws more and more interdependent, until it is almost impossible to say where one science begins and another ends. In time to come, as more and more light is vouchsafed, we may find that all natural phenomena are governed by a single ultimate comprehensive law, of which the actions of the human body and mind are but a very high expression. The gaps left unexplained by the law of evolution will be bridged and it will then no longer be a mystery how matter first originated, became endowed with life, and reached up to intelligence and to conscience. Human thought has not yet conquered these four problems, but the gradual advance and marvelous unity in the processes that we understand teach us that a leap in the scheme of nature is incredible.

The infinite variety that exists in nature is marvelous, but the infinite unity is much more marvelous. A multitude of animals and plants, each with its own peculiarities, exists, but the same life processes dependent upon the same simple principles, are found in them all. And the manner in which these are manifested is the whole of physiology. It has been customary to emphasize the differences that exist between organisms, but emphasis should rather be laid upon their similarity.

All organisms are composed of protoplasm, or living matter. What this protoplasm is we know only in part. We can analyze it chemically after killing it and thus find what elements are present in dead protoplasm. But what the subtle thing is which distinguishes this dead protoplasm from living protoplasm we do not know. Living protoplasm has the power to move, to grow, and to reproduce; and in this respect the protoplasm of the simplest animals and plants in no wise differs from the protoplasm of the highest animals and plants. The essential processes of physiology go on in the ameba as perfectly as in human beings, although the ameba is but a single cell not even possessing a definite cell wall. It can move from place to place; it can take in food and oxygen, carry these to any and all parts of its body and out of them make new protoplasm; it can give off waste materials, and it can produce its own kind. Physiologically human beings can do no more.

All living things may be divided into two classes, animals and plants. It seems easy to distinguish these from each other, for the higher forms that we meet

daily have developed definite and very different characteristics; but it is not easy to formulate a distinction that applies equally to the lower forms, for in the lowest animals and the lowest plants the living matter is so slightly differentiated, that in both its physiological qualities are manifested in the same way. They move readily from place to place, they make new protoplasm out of the non-living matter which they assimilate, and they reproduce their kind after the same methods. The only distinction which holds universally for both lower and higher forms concerns assimilation. Animals must have solid food. Plants can take in only liquids and gases, but out of these they manufacture within their bodies the complex solids that they too need.

Organisms may be again divided into two classes, those which are composed of a single cell and those which are composed of many cells. In one-celled forms there is no distinction between the cells of any particular species, they are all alike. Within the cell the protoplasm moves, assimilates food and manufactures new protoplasm; and the organism as a whole moves, assimilates food and reproduces new organisms. Thus the characteristics of living matter characterize the cell as an independent organism.

In many-celled organisms the cells differ from each other in appearance and work. The protoplasm in each cell has the qualities of living matter; it moves, assimilates food, and reproduces itself; but the cells are not independent organisms. They are associated with each other in groups called tissues and organs, and each group does its work toward maintaining the life of the

organism. The sum of these activities represents the activity of the independent organism, the particular way in which the many-celled organism as a whole shows its living characteristics, motion, reproduction, assimilation.

In different organisms the differentiation of the cells, tissues, and organs, has proceeded along different lines, or, proceeding along the same line, has reached different stages of development. According to the resulting peculiarities animals are divided into groups. Each group of organisms has its own peculiar way of moving from place to place, of assimilating food, and of reproducing its kind. These characteristics can not differ essentially in the various groups, for an organism can not assume characteristics other than those of the living matter which composes its cells; but they may differ in details, and these details depend on the peculiar arrangement of the cells of its body into tissues and organs, and the extent of their differentiation.

Some organisms have developed special organs for locomotion whose activity is governed by mechanical principles. To know how an animal moves from place to place, then, we must know how the organs of locomotion are constructed. Some animals have special means of protecting their young until they can fend for themselves. The more highly developed the animal, the longer is its period of infancy and the more perfect the arrangements for protection. We must know, then, something about the special organs set apart for reproduction and something about the habits of the group. As animals increase in complexity, the digestive appa-

ratus becomes more complete in its details and special arrangements for breathing are developed. We must know the structure and location of these organs in different groups in order to understand the conditions under which they do their work. We must know what the animal eats, how it eats, how the food is digested, absorbed, converted into protoplasm, and how the wastes are given off. These things happen in all animals and are governed by the same principles.

To study any particular animal, then, we study the peculiarities of structure which control its method of moving, its method of assimilation, and its method of reproduction.

# CHAPTER VII

## PROTOZOA

**Habitat.**—Protozoa, or one-celled animals, exist in great numbers. They vary greatly in shape, appearance and habits. They are found in stagnant water, in fresh water, in the sea, in moist earth, and as parasites in the bodies of other animals. Malaria is due to one of these forms which becomes parasitic in the bodies of human beings. The common forms may be obtained for study by filling shallow glass dishes with water plants, covering them with water and allowing them to decay. Within two weeks if the water is examined from time to time many different forms will be found.

**The Ameba.**—The simplest of these animals is the ameba. It has not even a cell wall. It is nothing but an undifferentiated mass of granular protoplasm containing a nucleus. It moves from place to place, grows, and reproduces, but in the most primitive way. Food is taken in at any point, indigestible materials pass out at any point, and any part of the cell is used for locomotion. (Figs. 4, 16.)

The irritability of the protoplasm is responsible for locomotion. The protoplasm flows within the cell and as there is no confining wall the position and shape of the

cell depend upon the direction and the amount of the flow. If the protoplasm touches food it flows around the particle, engulfs it, and after the nourishing part has been assimilated, flows away, leaving the residue behind. The animal thus moves from place to place and eats by means of projections of flowing protoplasm that appear and disappear at any point of the constantly changing outline. The ameba does not differ from other members of the group in its method of assimilation and reproduction.

**More Highly Specialized Forms.**—Other one-celled forms are more highly developed. A delicate wall surrounds the protoplasm, making the outline of the cell definite. Different regions are specialized for the performance of special work. The surface is more or less covered with fine, hair-like appendages called cilia which by their movement propel the animal from place to place as oars propel a boat (Fig. 72). At a definite point is an opening comparable to a mouth, surrounded by a circlet of cilia. This opening leads through a short passageway, comparable to a gullet, into the protoplasm.

The food consists of the bodies of smaller organisms. They are caught in the whirlpool formed by the movement of the cilia about the mouth and are drawn through the gullet into the body, where they may be seen with the aid of a compound microscope (Fig. 73).

**Food Substances.**—The protoplasm of these organisms contains the food substances which all animals require—water, salts, carbohydrates, fats and proteids. Surrounded by a drop of fluid these are carried about in the stream of circulating protoplasm until they are

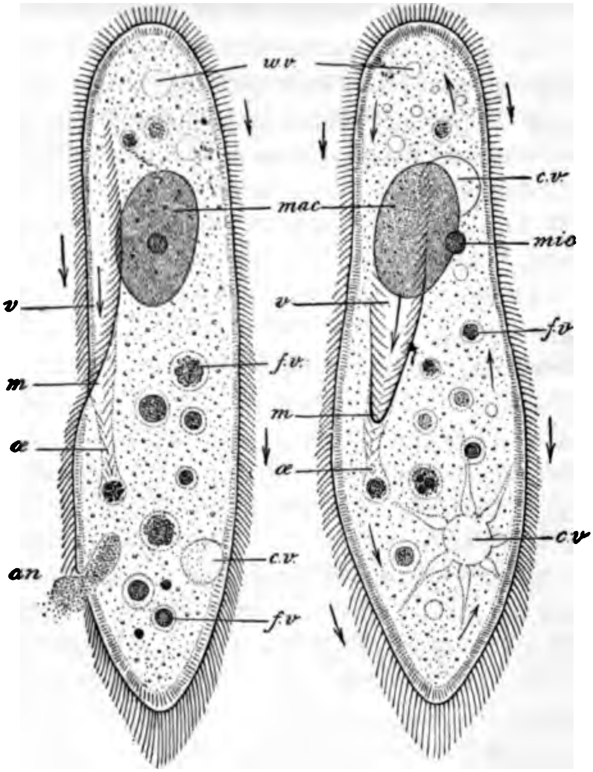



FIG. 72.—Paramecium. *A*, from the left side, anterior end directed upwards; *B*, from the ventral side, anterior end directed upwards; *an*, anal spot; *c.v.*, contractile vacuoles; *f.v.*, food-vacuoles; *w.v.*, water vacuoles; *m*, mouth; *mac*, *mic*, nucleus; *æ*, œsophagus; *v*, vestibule. The arrows inside indicate the direction of the protoplasmic currents, those outside the direction of water currents caused by the cilia. (From Sedgwick and Wilson.)

digested. The nutritive portion is thus brought to every part of the body where it may be used for the manufacture of new protoplasm, and the indigestible refuse to a weak spot in the body wall through which it is ejected.

**Wastes.**—The constant activity of these animals involves constant disintegration of protoplasm, and new protoplasm to take its place must be constantly made from the food substances. This involves a series of

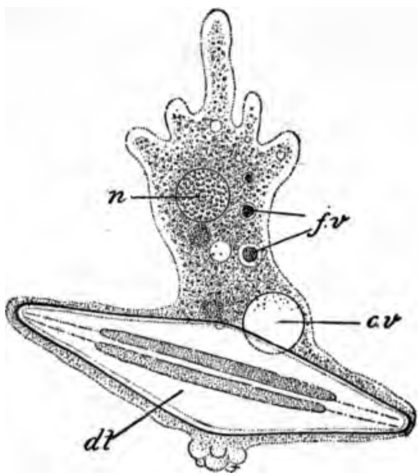



FIG. 78.—*Ameba* after a full meal, consisting of a large diatom (*dt*); *n*, nucleus; *f.v.* food vacuoles; *c.v.*, contractile vacuoles. (From Sedgwick and Wilson, after Leidy.)

chemical actions. Complex unstable substances disintegrate and new unstable substances are built up and in the process stable substances are formed. These stable substances can no longer be used by the body either for the manufacture of protoplasm or for the production of heat. They are therefore given off as wastes. The principal wastes are carbon dioxide and water vapor

which are given off by osmosis; and urea which is given off in solution by the contractile vacuole.

This organ is a true excretory organ, comparable to the kidney of the higher forms. It is a clear space which appears and disappears rhythmically, enlarging as it becomes filled with fluid and contracting to eject the fluid from the body. This organ must not be confused with the anal spot. The excretory organ gives off waste from the protoplasm itself, but from the anus pass off those parts of the food which can not be made into protoplasm and which therefore have never been a part of the body of the animal.

**Respiration.**—In one-celled animals the entire body wall is surrounded by water which contains oxygen in solution. By the process of osmosis oxygen passes into the body at any point and carbon dioxide passes out. This occurs not because the animal needs oxygen, but because a gas passes in the direction of the least pressure. The animal has no choice in the matter.

**Reproduction.**—Two methods of reproduction exist. The simplest of these is fission, a purely non-sexual process by which an animal splits into two parts each of which becomes a new animal. This process can not continue indefinitely. It is supplemented by a sexual process called conjugation. Two animals come close together and exchange either the whole or a part of the nucleus and separate. This brings about a rejuvenation by which both animals regain the power of fission. They are then able to divide and again divide until enough cells are formed to make a well-differentiated animal were they but joined together. As a rule con-

jugation takes place between two similar individuals, but in Vorticella and a few allied forms it is modified in such a way that it directly foreshadows the fertilization of higher forms. A bud is given off from


FIG. 74.—One of the vorticellidæ (Epistylis) in budlike conjugation. *r*, buds arising by division; *k*, a bud conjugating. (From Hertwig, after Greeff.)

the side of an individual, which divides into eight tiny motile cells. Each of these attaches itself to a full-sized individual and is completely absorbed by it (Fig. 74). The resulting cell regains the power of rapid cell division.

**Summary.**—Protozoa are microscopic, one-celled animals in which one cell performs all the functions. The cells of any particular species are not differentiated from each other, but within the cell special cell-organs may develop. Protozoa are able to move from place to place by means of flowing protoplasm or by means

of cilia. They assimilate the bodies of other organisms which contain all the necessary food substances; give off nitrogenous wastes through a special excretory organ; breathe through the entire surface of the body; and reproduce non-sexually by fission and sexually by conjugation.

# CHAPTER VIII

## CŒLENTERATA

**Many-Celled Animals.**—Many-celled animals probably owe their existence to some accident which prevented complete fission. The cells after division remained attached. Those that were subjected to different environment assumed different functions, and became different in structure. Those which developed a similar structure with power to do the same kind of work became banded together in groups called tissues or organs.

Many-celled animals have in this way developed certain characteristics in common. The cells of which they are composed have been subjected to the same kind of influences and have undergone development in the same general directions. In all many-celled animals, therefore, the same tissues are present. When these tissues are once established their development becomes one of degree, not of kind, and the quality of the work that they are able to accomplish becomes dependent merely on the degree of development.

**The Primary Layers.**—The cells were first arranged in two layers. The outside layer, or ectoderm, formed the skin and was protective in nature; the inside layer, or entoderm, formed the lining of the digestive tract and

assumed the functions of digestion and absorption of food substances. For some time probably animals remained in this primitive stage; there is still in existence a large group which has never passed beyond it. Later a third layer, the mesoderm, developed between the ectoderm and the entoderm, and the three primary layers were established. All higher animals pass through the layer stage in their development. From these layers are developed their highly organized tissues; from the ectoderm the protective organs,—skin and its appendages, nerves and sense organs; from the entoderm everything which has to do with alimentation,—digestive tract, digestive glands, lungs; from the mesoderm, everything else,—bone, muscles, blood, connective tissue, many glands.

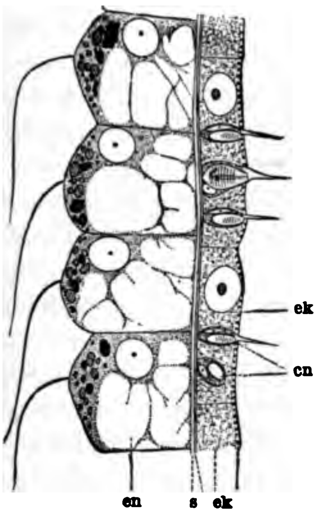



FIG. 75.—Section of wall of hydra. *cn*, nettle cells; *ek*, ectoderm; *s*, supporting layer; *en*, entoderm. (From Hertwig, after Schulze.)

**Tissues of the Cœlenterata.**—In the cœlenterata all the functions of the body are performed by the two primary layers (Fig. 75). The third layer is rudimentary. This group of animals is particularly interesting because it is transitional. Within it most of the tissues found in higher organisms are established. We have the beginning of muscle tissue,

nerve tissue, sense organs, the skeleton, a definite alimentary canal, and definite reproductive organs.

**Distinguishing Characteristics.**—The name cœlenterata comes from two Greek words that mean hollow intestine. It was given to the group because of the prominent digestive cavity which occupies the whole of

FIG. 76.—Hydra showing tentacles and the enlargements which give rise to the sperm and egg cells. (From Hertwig.)

the interior of the body, to the exclusion of the separate and distinct body cavity which exists in most of the higher forms. This common characteristic marks the relationship between such apparently diverse forms as the hydra, the jellyfish, and the sea anemone (Figs. 76, 77, 78). In the hydra there are only two layers of cells and these are arranged in a double, bell-shaped wall so

that a central space is formed with one opening to the outside.

The jellyfish is closely related to the hydroid (a salt-water form very similar to the fresh-water hydra) but

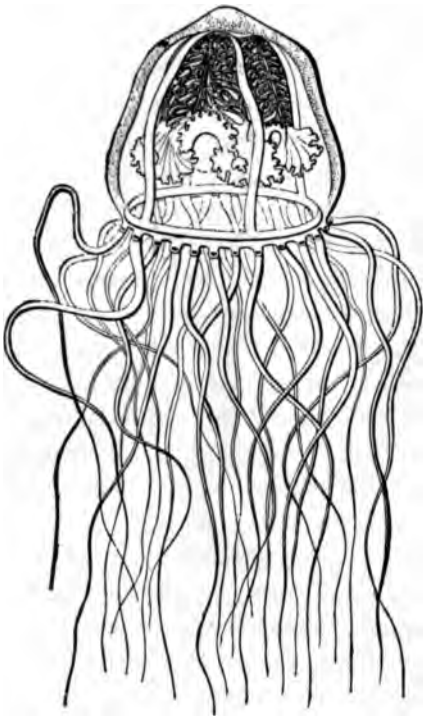


FIG. 77.—Jellyfish. (From Hertwig, after Haeckel.)

the resemblance has been obscured, for the depressions and elevations on the surface of the hydroid have been intensified in the jellyfish, and through the separation of the two layers in the wall by a structureless jelly

the central cavity has assumed a definite tubular shape (Figs. 79, A; 79, B).

In the sea anemone the middle layer, or mesoderm, is more highly developed than it is in the jellyfish, and

FIG. 78.—Diagram of sea anemone. (From Kingsley, after Emerton.)

it does not have the jelly-like character. The central cavity is more like that of the hydra except that the elevated hypostome is pushed in and hangs down as an œsophagus inside the animal. It is held in place by partitions having long attached filaments that assist in the digestion of the food (Fig. 79, C).

**Assimilation.**—In this group the first step in the development of the digestive system is taken. The tract may be described as a blind tube with a single opening

to the outside through which food enters and waste is ejected.

Guarding this opening is a circlet of tentacles, highly developed, contractile organs. In the tentacles are de-

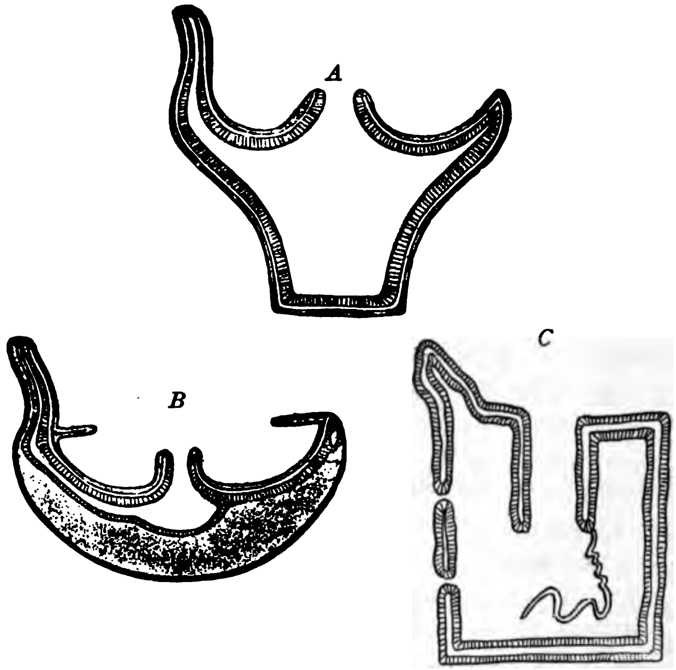



FIG. 79.—Diagram of sections of *A*, hydroid ; *B*, jellyfish ; *C*, sea anemone. (After Hertwig.)

veloped nettle cells, each of which has a little tube coiled in it which can be thrown out when the cell is stimulated. The tubes set free an irritating poison which paralyzes smaller animals and serves not only as a means of defense but aids in the capture of food.

Through the contraction of the tentacles the food is forced into the cavity. Partial digestion takes place there. Non-nutritive substances pass off through the opening; the nutritive portions are engulfed by the entodermal cells, which have the power of sending out ameboid branches. Complete digestion follows in the entodermal cells, and the products pass from cell to cell by osmosis. (Fig. 75.)

As the digestive tract extends to all parts of the body food is distributed without the intervention of a special circulatory apparatus. It therefore performs the office usually performed by blood vessels.

Breathing takes place through the outer cell walls. Oxygen dissolved in the water passes by osmosis into the cells and carbon dioxide formed in the cells passes into the surrounding water.

**Irritability.**—In addition to the ameboid motion of the entodermal cells and the spring-like motion of the nettle cells, the cells of both ectoderm and entoderm send out contractile branches which foreshadow the muscle cells in higher forms. The simultaneous contraction of these branches forces the animal to contract as a whole or allows a curious form of locomotion from place to place.

Some forms move about freely, some are fixed firmly, and some are able to hold fast to a support by suction. The jellyfish moves by the rhythmical contraction of its swimming bell. The bell relaxes and the hollow becomes filled with water, it contracts and the water is forced out. As this occurs rhythmically the animal moves jerkily through the water. The sea anemone at-

taches itself by flattening its surface against a rock until the air is forced from beneath. The pressure of the air

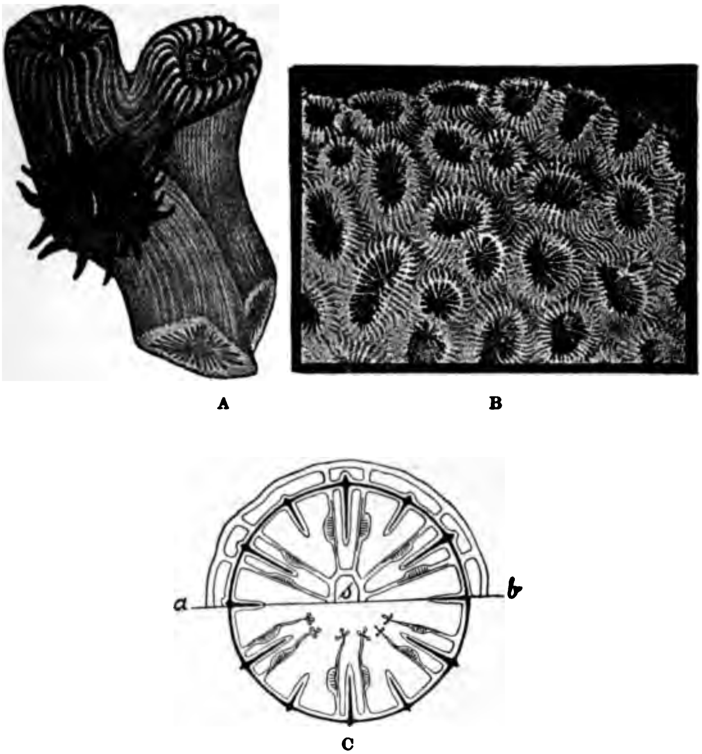



**Fig. 80.**—*A*, Coral showing living animal. (From Hertwig, after Heider.) *B*, Coral skeleton. (From Hertwig, after Klunzinger.) *C*, Diagrammatic section of coral showing flesh; above the line, *ab*, the section passes through the œsophagus, *s*; below the line it is lower down; the coral skeleton is black. (From Hertwig.)

above then holds it to the rock. By muscular contraction it is able to creep slowly along.

**Fixed Forms.**—Hydroids and corals are firmly at-

tached, usually by the formation of a supporting skeleton. In many hydroids a hard wall is formed on the outside of the animal, but in corals it is internal as well (Fig. 80). These animals can not move from place to place, but they can contract the soft part of the body. Corals are like sea anemones in structure except for the skeleton formed in corals by the deposit of calcareous salts in the mesoderm.

**Nervous System.**—Most of the fixed forms have no nervous system; the surface of the body is, however, extremely sensitive to contact. The motile forms have a definite nervous system composed of a central nerve ring from which branches are given off. Some of them have also simple sense organs which are sensitive to light and sound vibrations.

**Colonial Forms.**—Many forms develop buds which do not become detached; these grow into distinct individuals, which live together in a colony. Frequently members of a group formed in this way become adapted to the performance of special work, and the colony comes to resemble a more highly-differentiated, many-celled animal. It becomes a question then whether the whole colony is to be regarded as a collection of separate individuals which live together for the common good, or as a single animal with exceedingly well-developed parts (Fig. 81).

**Reproduction.**—In all of these forms reproduction is either non-sexual (by budding, a process allied to fission) or sexual (by the union of dissimilar cells). In budding a mass of cells grows out with the power to develop into a new individual which may, or may not,

be cut off from the parent. The sexual process does not differ in essence from the conjugation of the one-celled animal, but it is necessarily modified by the fact that in a many-celled animal as the cells are

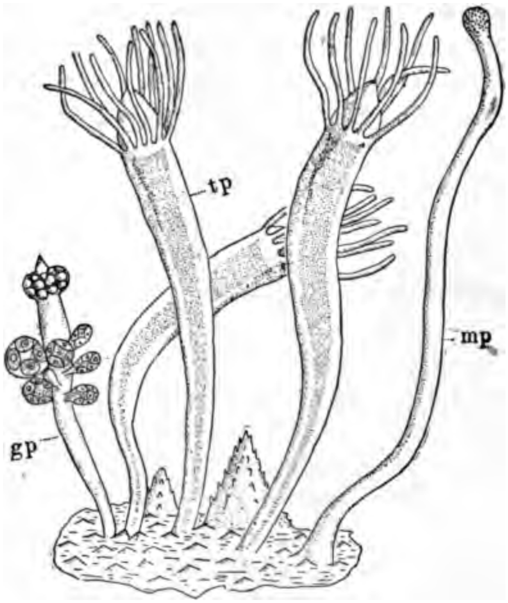



FIG. 81.—Portion of a colony. *gp*, reproductive polyp; *mp*, defensive polyp; *tp*, nutritive polyp. (From McMurrich, after Hincks.)

differentiated not all of them can enter into the process. Special cells are therefore manufactured by special organs and set apart for reproduction. In one animal they are large, round, quiescent; and in another they are small, irregular, motile. These cells are set free in the water. They meet as the one-celled animals do

and unite, forming new cells with the power of cell division and cell differentiation (Figs. 54; 55, A).

**Alternation of Generations.**—In addition to the form relationship there is a very curious parental relationship

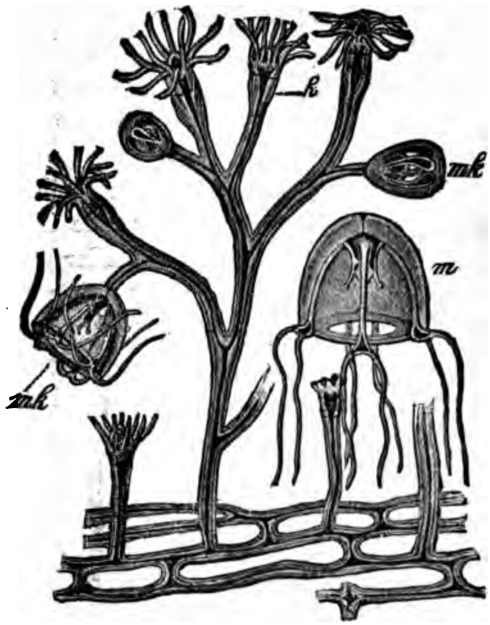



FIG. 82.—Hydroid showing alternation of generations. *h*, polyps which have given off medusa buds; *mk*, medusa buds; *m*, separated medusa. (From Hertwig, after Lang.)

between the hydroid and the jellyfish. The hydroid is colonial. The individuals increase in number on the common stalk by continual budding. Some of these buds break off and become free-swimming jellyfish which assume a sexual character. They produce eggs and sperm which unite, divide, and differentiate to form

animal, irritability, assimilation, and reproduction, manifest themselves.

**The Starfish.**—Perhaps the best-known echinoderm is the starfish. It has a symmetrical, flattened, star-

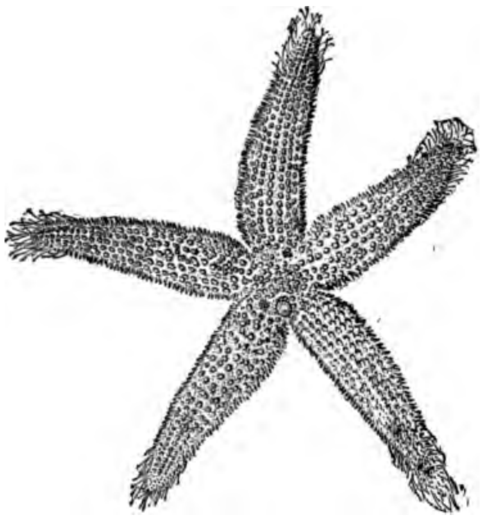


FIG. 83 A.—Starfish, dorsal surface. (From McMurrich.)

shaped body (Fig. 83 A) with, as a rule, five rays, though there may be as many as twenty. It is covered with a protective skeleton made of movable plates which allow the rays to bend easily in any direction. A mouth is in the center of the ventral side (Fig. 83 B). On this side, in each arm, is a groove in which are situated the locomotor organs, commonly called tube feet. These tubes are connected with a system which is a peculiar characteristic of the echinoderms.

**Symmetry.**—The similarity of the rays of the star-

fish has given rise to the phrase radial symmetry. Symmetry involves a repetition of similar parts. Externally the arms of the starfish radiate from a common center

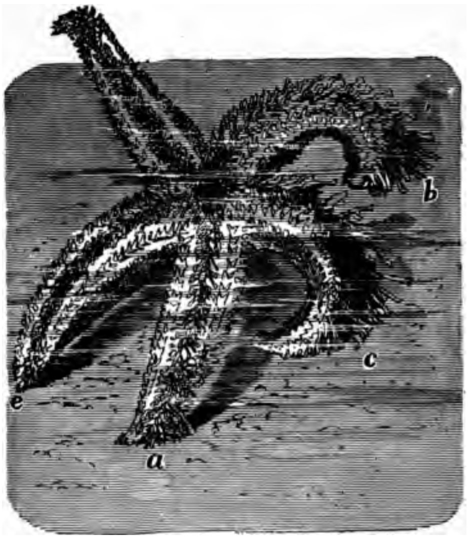



**FIG. 88 B.—Starfish, ventral surface (placed on back, righting itself). (From Packard, after Romanes.)**

and except for the perforated plate on the dorsal surface the five parts of the body duplicate each other. Internally the organs are correspondingly repeated. The perforated plate gives the body a rudimentary two-sided or bilateral symmetry, for a line drawn through this plate to the tip of the opposite ray divides the animal into two similar halves.

**Internal Structure.**—The alimentary system is a tube open at both ends that passes through the animal dorso-

ventrally (Fig. 84). It has two enlargements which somewhat obscure its tube-like character, each of which is made of five pouches, one for each ray. The pouches of the thin-walled stomach on the dorsal side are further subdivided, and are continued to form the ducts of the hepatic glands, or livers, found in each ray. The other organs are also arranged with reference to the digestive tract. The nervous, circulatory and water-vascular systems take the form of rings which surround the œsophagus and give off an arm for each ray. At the end of each radial nerve is a sense organ called an eye-spot that is sensitive to light.

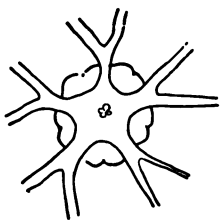


FIG. 84.—Dorsal view of the alimentary canal of a starfish. Diagrammatic.

**Irritability.**—Irritability manifests itself in change of form and position and in movement from place to place through the activity of muscles whose cells are specially modified for contraction. These are aided by nerves whose special form of irritability consists in their power of carrying stimuli quickly. They thus increase the rapidity of movement.

**Mechanics of Locomotion.**—In moving from place to place, a starfish contracts the muscles which bend a ray. The ray moves in a definite direction and then holds fast by means of its tube feet until the body of the animal is adjusted to the new position. The tube feet stiffen, and force the air from beneath them. They are then held fast to the damp surface by the weight of the surrounding air. The pressure exerted on them by the air may be found approximately by comparing the ap-

proximate area of the bottom of all the little tube feet involved with a square inch and multiplying the result by fifteen, for every square inch of surface bears the weight of fifteen pounds of air.

The tube feet are able to stiffen because of their connection with a system of tubes in the animal. Surrounding the œsophagus is a tubular ring which gives off a blind tube in every ray and in addition a tube with calcareous walls that opens to the outside on the dorsal side in a perforated plate. Each radial canal gives off at regular intervals pairs of canals which connect with the tube feet. These are hollow muscular tubes each of which ends inside the ray in a little sac and outside the ray in a sucker (Fig. 85). The system is filled with fluid. If the sacs contract fluid is forced into the feet and they stiffen, if the feet contract the fluid is forced back into the sac and the feet are withdrawn.

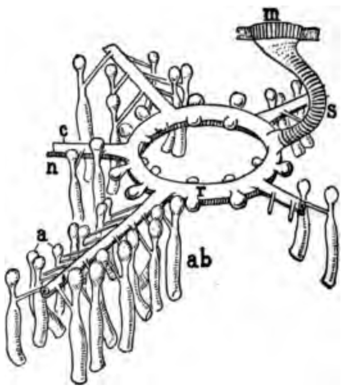



FIG. 85. — Water-vascular system of starfish. *a*, ampullæ or sacs; *ab*, tube feet; *c*, radial canal; *m*, perforated plate; *n*, radial nerve; *r*, ring canal; *s*, stone canal. (From Hertwig.)

**Assimilation.**—Assimilation takes place through the respiratory system and the alimentary canal. Special organs for the absorption of oxygen are developed on the dorsal surface in the form of gill-like outgrowths. Water passes over them and the oxygen it contains

may be developed to such an extent that an animal may bury itself deeply in mud or in piles and yet get the necessary food and oxygen (Fig. 90).

FIG. 87.—Various forms of shells. (From Hertwig.)

**Gills.**—In the space between the mantle and the body extend on each side two other folds of skin called gills. They are very thin and are permeated with thin-walled blood vessels by means of which blood is brought into connection with oxygen dissolved in the water.

In land molluscs gills are absent, but the walls of the mantle chamber are moist and lined with fine blood vessels. They act like lungs. As air circulates freely

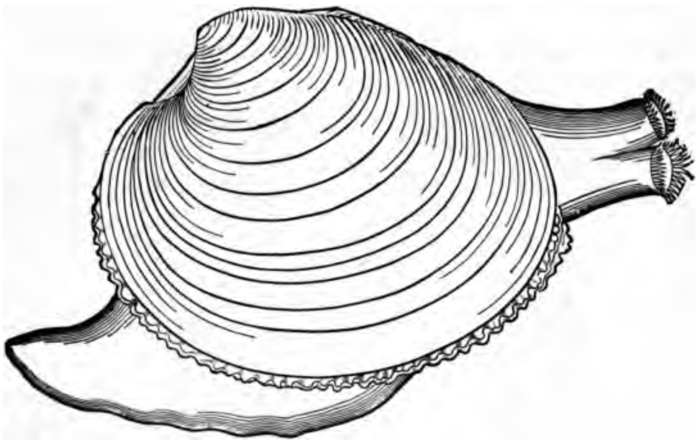


FIG. 88.—Clam with foot and siphons extended. (From Kingsley.)

through the mantle chamber, oxygen can pass into the blood and carbon dioxide from the blood into the air.

**Circulatory System.**—The body cavity is very small. It is practically reduced to the small chamber in which the heart is situated. The heart is divided into a ventricle which sends the blood over the body and an auricle which receives the blood from the gills. The system is not closed, the vessels open into large spaces or sinuses. In the squid an extra set of contractile organs called branchial hearts situated at the base of the gills force the blood to pass through the gills.

**Alimentary Canal.**—The alimentary canal is a well-developed tube. On its way through the body it passes

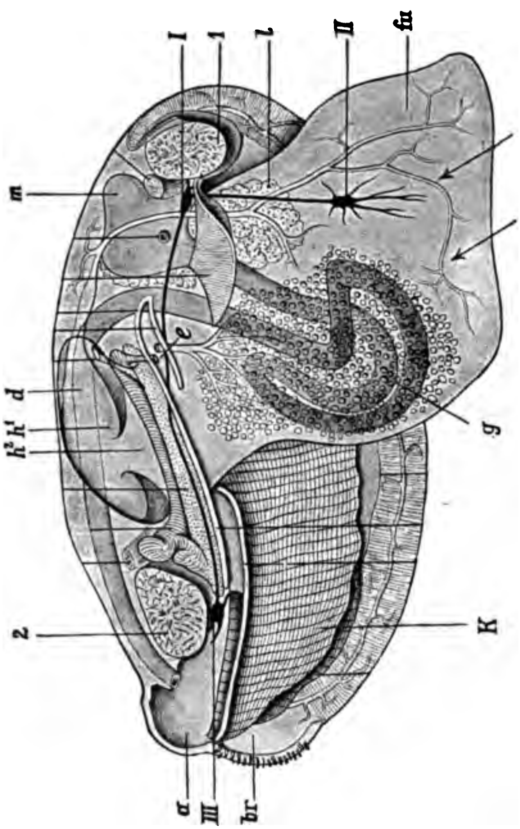



FIG. 89.—Anatomy of the fresh water mussel, the mantle, gill, and liver of the right side removed, the pericardium opened. 1, 2, muscles; *I*, *II*, *III*, ganglia; *a*, anus; *br*, branchial siphon; *d*, intestine; *e*, nephridial opening; *fu*, foot; *g*, reproductive organ; *h*1, *h*2, ventricle and auricle of heart; *K*, gill; *l*, left liver; *m*, stomach. (From Hertwig.)

directly through the heart. In some forms it is so bent on itself that it ends close to the mouth. A well-developed liver and very large sexual organs fill the remaining space.

**Nervous System.**—The nervous system consists of three pairs of ganglia connected by cords. These are associated with three sets of sense organs, sensitive to light or sound vibrations. The eyes vary from mere spots sensitive to light which may be situated on the mantle, the siphon, the tips of the tentacles, or the back, to the well-developed eyes of the squid which are situated on the side of the head and are almost as well developed as the human eye.

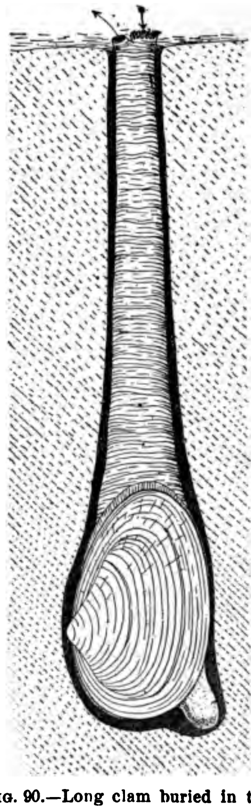


FIG. 90.—Long clam buried in the mud. (From Kingsley.)

**Economic Value.**—Molluscs have great economic value. Clams, oysters and scallops are highly prized for food. The precious pearl is formed by the oyster. The oyster and the abalone furnish the mother of pearl used extensively in the manufacture of such articles as buttons and knife handles. The ink that is found in squids is used in the manufacture of sepia. It is useful to

# CHAPTER XI

## VERMES

**Irritability of the Earthworm.**—The most widely known representative of this group is the common earthworm. Every one is familiar with its elongated, symmetrical, curiously-ringed surface. It is extremely irritable and when stimulated it moves readily and quickly. It has no definite sense organs, but a tactile sense is widely distributed over the surface of its body and it is so sensitive that it responds even to sound vibrations.

**Mechanics of Locomotion.**—Movement from place to place is controlled mechanically by a definite arrangement of muscles. The worm lifts its anterior end and stretches, thereby becoming long and narrow. It puts down this end and holds fast. It then lifts the posterior end and by becoming short and thick draws it forward. This end then holds fast and the anterior end again stretches. Through repetition of this process the animal progresses. Two sets of antagonistic muscles control this alternate elongation and contraction. They are arranged so that one set runs lengthwise through the body while the other set encircles it. As one set contracts the other set relaxes. When the longitudinal muscles contract and the circular muscles relax, the worm becomes short and thick; when the circular muscles con-

tract and the longitudinal muscles relax, the worm becomes long and thin. It holds fast by means of stiff hairs called *setæ* (Fig. 92) which are planted in such a direction that the animal can not move against them.

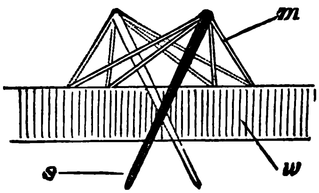



FIG. 92. — Diagram to illustrate the action of the setæ. *m*, muscles; *s*, seta; *w*, body wall. Dotted lines represent the position of the seta and its muscles when bent in the opposite direction. (From Sedgwick and Wilson.)

**Surface Characteristics.**—These setæ may easily be seen with the unaided eye stretching in two double rows the length of the ventral surface (Fig. 93). Also on this surface are little swellings that mark tiny openings. These are situated between the ninth and tenth, between the tenth and eleventh, on the fourteenth and on the fifteenth rings. The mouth is under an overhanging lip at the anterior end, and directly opposite in the posterior end is the anal opening. A swollen girdle encircles the middle of the body.

One line only can be drawn on the surface that will divide the worm into two similar parts. It is therefore bilaterally symmetrical. The repetition of similar rings throughout its length gives it another kind of symmetry called serial symmetry. As in the starfish this external repetition of similar parts indicates a corresponding internal repetition.

**Assimilation.**—A slit down the dorsal side of the animal and a few pins to hold the flaps of skin open will lay bare the interior of the animal. The alimentary canal, which is plainly a tube open at both ends, extends

with the wave-like contraction of the dorsal vessel cause the blood to circulate.

**A Segment.**—Corresponding to the external rings are thin partitions called septa or dissepiments that separate the body into little compartments called segments. Except for those in the anterior end that contain the reproductive organs and the aortic arches, the segments

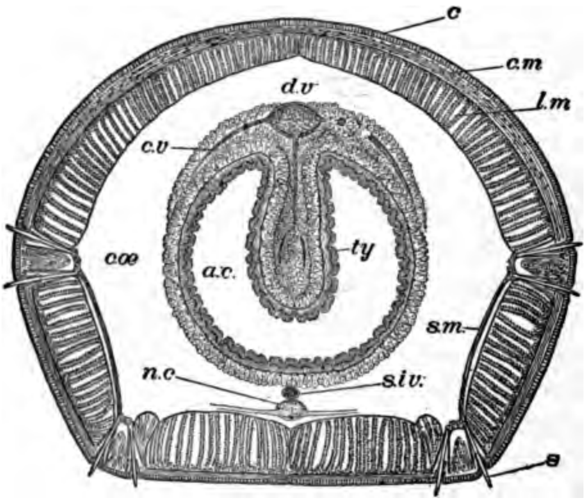



**Fig. 97.**—Cross section of the earthworm. *a.c*, cavity of the alimentary canal; *c*, cuticle; *c.æ*, cœlom; *c.m.*, circular muscles; *c.v*, circular vessel; *d.v*, dorsal vessel; *l.m.*, longitudinal muscles; *n. c*, ventral nerve-chain; *s*, seta; *s.i.v*, subintestinal vessel; *s.m.*, muscle connecting seta of the same side; *ty*, typhlosole. (From Sedgwick and Wilson.)

are alike (Fig. 97). Each one contains a section of the longitudinal muscles, a circular muscle, two pairs of setæ, a ganglion with its pair of nerves, a circular blood vessel with sections of the longitudinal vessels, a section of the alimentary canal and a pair of nephridia.

**Excretory Organs.**—The nephridia, kidney-like excretory organs, are responsible for the elimination of nitrogenous waste. Each of them is a curiously twisted tube which opens to the body cavity through a funnel-shaped end and empties to the exterior through the other end (Fig. 96).

**The Nervous System.**—The nervous system extends the length of the body on the ventral surface. It is a cord with a small swelling or ganglion in each segment, made of two cords only partially joined. This is particularly interesting because in some of the other worms the two cords are entirely separate and lie on opposite sides of the body. At the anterior end these cords separate and pass in a ring around the alimentary canal. The juncture on the dorsal side is marked by a double ganglion. The serial arrangement of the ganglia in the ventral cord is very important, for on it those people who trace the ancestry of the vertebrates to the segmented worms base their claim. In higher animals the spinal cord retains this characteristic even when the body shows no other trace of segmentation (Figs. 70, 71).

**Reproduction.**—The arrangement by which the eggs and sperm come in contact with each other is extremely interesting. They can not be turned loose as in aquatic forms, for the delicate eggs and sperm would die if they were left unprotected on the ground. The openings seen near the ninth and tenth segments lead into little sacs called seminal receptacles situated two on each side. In the thirteenth segment tiny ovaries which produce the egg cells lie one on each side. These open to the outside on the fourteenth segment. Near them are the

large vesicles which surround the spermary or testis. These have three large lobes on each side and open to the outside on the fifteenth segment.

The worm is hermaphroditic, that is, both eggs and sperm are present in the same animal, but self-fertilization is prevented by the arrangement of the organs and by the fact that the eggs and sperm do not mature at exactly the same time in each animal. Cross fertilization takes place in the following way. In the breeding season two animals come close together with the ventral surfaces touching, the anterior end of one directed toward the posterior end of the other. The ninth segment of one thus comes in contact with the fifteenth of the other, bringing the opening of the male organs directly opposite the opening of the seminal receptacles. Sperm cells then pass from each worm into the seminal receptacles of the other. The worms then separate. When the eggs become ripe the ring, or clitellum, noticed around the middle of the worm begins to pass forward. When it reaches the fourteenth segment the eggs pass into it. When it reaches the ninth and tenth, sperm cells obtained from another worm pass into it. It continues to pass forward until it slips over the head. By contraction the ends close; a capsule has then been formed which contains sperm and eggs belonging to different individuals. They unite and cell division and differentiation follow.

**Classification.**—The Vermes, or worms, are a large group of animals that differ from each other materially. Their bodies are elongated and bilaterally symmetrical, with a marked distinction between the dorsal and ventral

surfaces. There is no internal skeleton and the appendages are not jointed. They are divided into four classes, the flat worms, the round worms, the segmented worms, and the *molluscoidea*. These groups differ from each other so much that it is probable that their association is an artificial grouping made for convenience.

**Flat Worms.**—The flat worms may be free, living in water or moist earth, or parasitic. The body is flattened and has no appendages. There is no body cavity separate from the digestive system. In lower forms the alimentary canal has only one opening. In parasitic forms the alimentary tract may be completely lost. There is a small dorsal brain, and two nerve cords run backward parallel to each other. Eyes may be present on the dorsal surface near the brain. Some of these worms reproduce by fission. A new mouth appears, the body contracts in front of it and finally divides into two worms. Before one division is complete new divisions may begin, until a chain of as many as eight worms may be hanging together. There is also a sexual reproduction. The parasitic forms are often responsible for disease in man and other animals. They enter the body in the food or water. The tapeworm is of these perhaps the best known.

**Round Worms.**—The round worms are long, and as the name indicates, cylindrical, and the surface is covered by a tough cuticle. The alimentary canal opens to the outside at both ends. Some forms live in water and some are parasitic in plants and in animals. Trichina is particularly dangerous. It enters the body in uncooked pork.

**Segmented Worms.**—The segmented worms have already been fully described. Some of them are free and some live in tubes. Some live in the water and have well-developed heads bearing tentacles and eyes. Fleshy outgrowths on the surface of the body are used for swimming. The young undergo a metamorphosis similar to that of the molluscs. Leeches have sucking discs and they have been used by physicians to draw blood from the body when it was thought that a disease might be cured by weakening the patient.

**Molluscoidea.**—The molluscoidea were once thought to be molluscs. They have an alimentary canal that is open at both ends and there is a circle of tentacles around the mouth. Some of them produce large colonies by budding. Some have a bivalve shell through which a stalk projects which is fastened to some support. All of them reproduce sexually.

# CHAPTER XII

## ARTHROPODA

**External Characteristics.**—The Arthropoda include a great number of apparently divergent forms such as lobsters, spiders, flies, but their common characteristics are well-defined. The name means jointed-foot, and the class includes those animals which have an external jointed skeleton and jointed appendages. As in the segmented worms an evident external segmentation is associated with an internal segmentation, that is, the body is divided into a series of segments each of which contains parts of the internal organs. Many of the segments are modified, however. Some of them are over-developed, some are under-developed and some are fused. The result is that different regions in the body become marked off, and it is not always easy to determine the number of segments that are involved. Usually three regions may be distinguished, the head which has well-developed sense organs, the thorax which bears the organs of locomotion, and the abdomen which may, or may not, bear appendages and may, or may not, show marked segmentation.

**Nervous System.**—These animals are highly developed and their tissues well differentiated. They are very irritable and respond readily to outside stimuli through

a well-developed muscular and nervous system. The nervous system is similar to that of segmented worms. It is made of a double ventral chain of ganglia connected with a nerve cord that divides at its anterior end, passes around the alimentary canal and unites on the dorsal side in a concentration of ganglia called the brain. Each segment contains a single ganglion which sends off two pairs of nerves to control the muscles and other organs of that segment. When the segments become fused the ganglia often become fused, but it is possible to determine the number of segments involved by counting the nerves that are given off.

**Digestive System.**—A well-developed alimentary canal open at both ends to the outside extends the length of the body. A large liver furnishes digestive juices.

**Respiratory System.**—Special organs are set apart for respiration which take the form of gills in those animals that live in the water and trachea, or air tubes, in those that are surrounded by air. The gills are outgrowths of the body wall covered with a thin, moist membrane and permeated with numerous blood vessels. Oxygen dissolved in the water and carbon dioxide in the blood pass readily through the membrane. Tracheæ are tubes which permeate the body and become filled with air. Oxygen can pass from the air in these tubes into the blood or directly into the tissues.

**Excretory Organs.**—There are two kinds of excretory organs, both of which take the form of tubes. The nephridia, sometimes called the green gland, or shell gland, are in the anterior part of the animal and open to the outside. The Malpighian tubes present in some forms

in great numbers open into the posterior part of the alimentary canal.

**Circulatory System.**—The circulatory system is more highly developed in some forms than in others, but it is never entirely closed. A heart lies dorsal to the alimentary canal. The blood passes from it through the arteries into great open spaces and from these it is sucked back into the heart through large openings. There is an intimate connection between the development of the respiratory and circulatory systems. The more localized the respiration, the more complete the circulation; the more it is diffused through the body the more closely oxygen is brought in contact with the tissues and the more the circulatory system is reduced.

**Sense Organs.**—Most of these animals are sensitive to sound vibrations and seem able to distinguish substances through taste or smell; but touch and sight are the most highly developed of the senses. The eyes are of two kinds, simple and compound. The compound eye is a collection of simple eyes closely united. Each simple eye sees part of the object. It is a tube with a sensitive surface at its base. The light from a single point is reflected through the tube and forms an image on the surface. The sum of the partial images makes the complete image.

**Reproduction.**—Reproduction takes place sexually. Sometimes individuals are hermaphroditic, in which case eggs and sperm are formed in the same animal; but usually the sexes are separate and to be distinguished by a difference in such external characters as color, size and form of appendages. The sexual organs are well-

developed and open to the outside through ducts that are probably modified excretory organs. The development of unfertilized eggs occurs in bees and a few other forms. In aquatic forms eggs and sperm meet in the water; but in aërial forms union of the reproductive cells takes place in the duct of the female.

**Appendages.**—The appendages are primarily locomotor in function, but they may be modified into sense organs, into chewing jaws or into false feet. The false feet serve as gills, as supports for gills, as places for the attachment of eggs, as organs for the transfer of sperm, or as swimming or creeping organs. The head bears the *antennæ*, or touch organs, the jaws and *maxillipeds; the thorax,* the true feet; and the abdomen bears the false feet or it lacks appendages.

**Classification.**—The Arthropoda are divided into four classes: the crustacea, the acerata, the insecta, and the myriapoda.

**The Crustacea.**—In the crustacea, gills are present, the feet are two-branched, and the reproductive ducts open near the middle of the body. They are divided into two classes, the first of which includes very small forms mostly microscopic whose bodies vary in the number of segments and in their appearance. The others are larger and their bodies consist of twenty segments. The best known examples are the shrimps, lobsters and crabs so much esteemed for food. Most of them are marine, but some live in fresh water and some live on land.

**Locomotion of the Lobster.**—The study of the Lobster (Fig. 98) is interesting because it so well illustrates the characteristics of the class and because it is

large enough to show the distinctive features without difficulty. It moves through the water by contracting the tail or abdomen. This part of the animal is sharply segmented and the plates of which it is composed slip

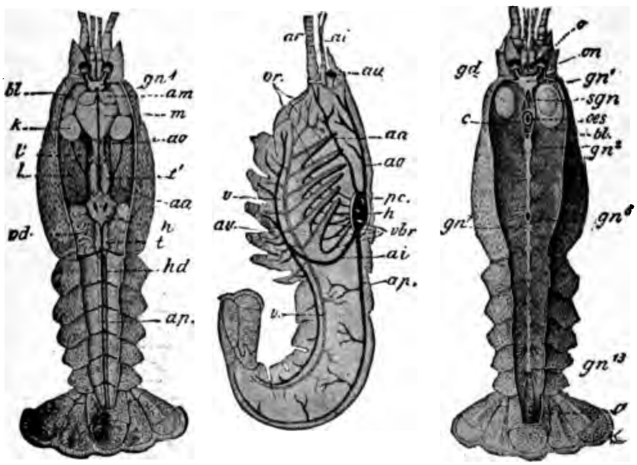



FIG. 98.—Anatomy of crayfish. *A*, dorsal surface removed; *B*, scheme of circulation; *C*, viscera removed, showing green gland and nervous system. *a*, anus; *aa*, hepatic artery; *ae*, antenna; *ai*, antennula, also sternal artery; *am*, muscles of stomach; *ao*, ophthalmic artery; *ap*, abdominal artery; *av*, ventral artery; *bl*, urinary bladder; *br*, gill arteries; *c*, œsophageal commissures; *gd*, green gland; *gn*, brain, ventral ganglia; *h*, heart; *hd*, intestine; *k*, mandibular muscles; *l,l'*, liver and its duct; *m*, stomach; *o*, otocyst; *œs*, œsophagus; *on*, optic nerve; *pc*, pericardium; *sgn*, sympathetic nerve; *t,t'*, testis or spermary; *v*, ventral blood sinus; *vd*, sperm duct; *vdr*, veins from gill to heart. (From Hertwig)

over each other so that when the animal flaps its tail a sharp bend takes place and the water is pushed ahead of it. At the same time the appendages move toward the head so that resistance is lessened and the animal moves rapidly backward. It spends a large part of its time on the rocks and moves over them very easily by means of the walking legs.

The joints in these legs are all hinge joints, but there are four or five in each leg and they are so arranged with reference to each other that the leg has the power of turning to the mouth. A rotary motion is thus possible comparable to that given by a single ball and socket joint to the human arm. These walking legs help to catch food and carry it to the mouth, where the heavy jaws crush it (Fig. 99). These animals are great scavengers, they eat organic material that contains the five food substances.

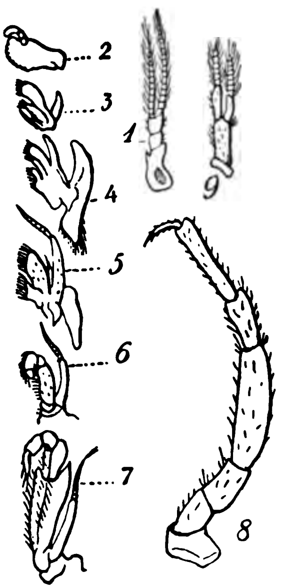



FIG. 99.—Appendages of the crayfish. 1, first antenna; 2, mandible; 3, 4, first and second maxillæ; 5, 6, 7, maxillipeds; 8, walking leg; 9, pleopod. (From Hertwig.)

**External Characteristics.**—The mouth at the anterior end of the body on the ventral side, the anus in the posterior end, and the reproductive openings on the base of the third or fifth pair of walking legs, are easily distinguished. The sense organs are very prominent, long *antennæ* and *antennules*, very sensitive to touch, and curious eyes elevated on stalks. On the base of the *antennules* are small openings that lead into organs sensitive to vibration. These are little sacs lined with sensory cells each of which bears a hair. Upon these hairs is balanced a tiny mass of calcium carbonate whose

slightest motion is communicated by the hairs to the cells.

**Moulting of the Shell.**—As the shell is hard and does not allow for growth it is moulted or cast off at intervals in order that the animal may grow larger. As soon as the hard coating is off, the animal at once expands; the tender skin which is thus exposed hardens after a time, and the process is repeated. The new skin repeats every peculiarity of the cast shell so that the surface marking remains the same. Crabs are found in great numbers immediately after they have shed the shell and in this condition are called soft-shelled crabs. Other forms are not found in this condition in sufficient numbers to make them important commercially.

**Digestive System.**—On the dorsal surface the alimentary canal extends the length of the body. At the anterior end it dips sharply and opens through the mouth on the ventral surface. At the dip is an enlarged stomach with hard walls that grind the food and pass it on into a softer stomach which digests it. If the animal is freshly killed contractions may be seen, passing like a wave the length of the intestine and forcing the contents toward the posterior end.

**Other Organs.**—Near the anterior end of the lobster are two nephridia-like excretory organs, called the green glands, which give off the waste from the protoplasm.

Two very prominent brownish glands act as a liver and pour digestive juices into the alimentary canal near its anterior end.

The heart, situated on the dorsal side, is a curious pentagonal structure with blood vessels passing off from

the corners. On its surface are large openings through which the blood re-enters the heart from the spaces into which it is poured. The blood is uncolored. It very quickly coagulates if a vessel is cut.

Underneath lie the large muscles used for food. They almost fill the abdomen and their segmental arrangement is evident at a glance. Their contraction gives the abdomen the powerful stroke by means of which a passage is forced through the water.

**Respiration.**—As the lobster is covered with a hard shell, a specialized moist membrane has been set aside for breathing. This membrane is confined to the surface of the gills, which lie under the free edge of the shell. Water is kept running over them by an appendage which moves in such a way that it causes a current. Oxygen is thus able to pass from the water through the thin gill membrane into the blood and carbon dioxide is able to pass from the blood into the water.

**Reproduction.**—The reproductive organs are very prominent, especially in the breeding season. The sexes are separate. The eggs pass out of the body through ducts that open usually on the base of the third (female) or fifth (male) walking foot and are held by the swimmerets, or appendages of the abdomen. While there they come in contact with sperm and begin their development. They remain there until the eggs are hatched and the young can shift for themselves. The little larvæ are unlike the parent but soon undergo the change which gives them the adult form.

**Segmentation.**—The nerve cord lies on the ventral

surface. As in the earthworm it has a ganglion and a pair of nerves for every segment. At the anterior end it passes around the alimentary canal in a ring. On the dorsal and ventral sides the juncture of the two parts forming the ring is marked by a concentration of ganglia. The number of ganglia involved may be found by counting the number of nerves given off. The total number of ganglia corresponds with the number of pairs of appendages and with the number of segments, so that the internal evidences of segmentation are in harmony with the external sign. It will be found exclusive of the eyes to be twenty.

**Acerata.**—The acerata lack antennæ. The body is divided into two parts, the cephalothorax which bears six pairs of appendages, and the abdomen which is without appendages. They breathe through gills, lungs or trachea, and the reproductive ducts open near the middle of the body. The best known representatives of the group are the scorpions, spiders, daddy-long-legs, ticks, mites, etc., that are such pests. In the spiders the cephalothorax and the abdomen are unsegmented externally but they are sharply separated. In front are the poison jaws and on the tip of the lower surface of the abdomen are two or three pairs of spinnerettes. These give off a fluid which hardens when exposed to the air. This is used to protect the eggs and to form the web that is used as a home and as a trap for prey.

**Myriapoda.**—To this group belong the centipeds and the millipeds. In it there is no distinction between the thorax and abdomen. The head is well-defined and is succeeded by a long series of segments which bear one

(centipeds), (Fig. 100), or two (millipeds), (Fig. 101), pairs of appendages.

**Insecta.**—(Hexapoda).—The study of insects is a science in itself. There are supposed to be more than a million distinct forms and more species than in all the rest of the animal kingdom. The body is divided into three distinct regions. The head bears the antennæ, the sense organs and the mouth parts. These are fitted for biting or for sucking. The thorax is made of three segments which may be movable. On it are three pairs of legs, and usually two pairs of wings, but these may be entirely missing or one pair may be reduced or hardened. The abdomen is made of ten segments, though the number may be reduced. It may be fixed to the thorax by its entire width or by a slender stalk. It may have three pairs of appendages, but these are never locomotor in the adult. They may be rudimentary or they may be transformed into the organ which is used for laying the eggs or for stinging. The sexes are separate.

Fig. 100.—Centiped.

The alimentary canal has few convolutions (Fig. 102). There is a chewing stomach and a true stomach.

The excretory organs take the form of Malpighian tubules which vary in number from two to a hundred. They open into the intestine.

The circulatory organs are poorly developed, but they are compensated for by the tracheæ. The number of tracheal openings on the side of the thorax and abdomen varies from three to ten, but there are never more than one for each segment. They branch internally again and again until the fine branches permeate every part of the body. Sometimes they are enlarged into air sacs which make the body light. Air is drawn in by a rhythmical enlargement of the abdomen and reaches all the tissues of the body. It is expelled again by the contraction of the abdomen.

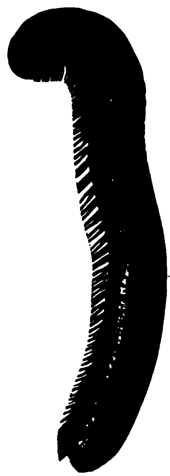


FIG. 101.—Milliped.

The alimentary canal passes between the two halves of the nerve cord which unite to form a dorsal ganglion, or brain, and a ventral cord. The eyes, simple and compound, are on the head. The organs for hearing may be on the base of the abdomen, on the legs or on the antennæ. Taste is on the lower lip and smell on the antennæ.

When the young leave the egg they are very small; they may have the adult appearance, or they may be like the adult except that the wings are small and later increase in size with every moult, or they may be entirely different from the adult, in which case they undergo a

larval metamorphosis. The larva is very active and eats voraciously, it molts again and again and then becomes quiet. During the quiescent stage it eats nothing, for important changes occur with which eating would interfere. Through these changes the adult form is gained.

The insects are divided into nine classes. The well-known forms that represent them are: (1) The silver

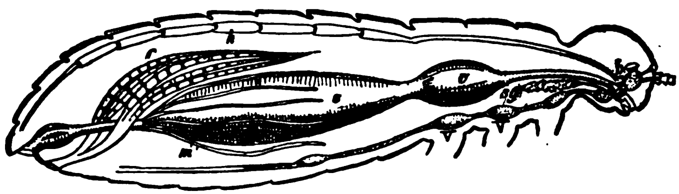



FIG. 102.—Diagram of the anatomy of an insect. *b*, brain; *c*, crop; *h*, heart; *m*, Malpighian tubes; *r*, reproductive organs; *s*, stomach; *sg*, salivary glands; *v*, ganglia of ventral chain. (From Kingsley.)

fish, which eat paper and starched clothing; (2) Grasshoppers, crickets, locusts, which may damage crops almost incalculably; (3) Dragon flies, may flies; (4) Caddis flies and ant lions; (5) Flies, mosquitoes, pests and carriers of disease; (6) Beetles, lady bugs, buffalo bugs; (7) Ants, bees and wasps; (8) Seventeen-year locust; (9) Moths and butterflies, whose larvæ often damage crops.

# CHAPTER XIII

## VERTEBRATA

**Irritability.**—In vertebrates (e.g. fish, birds, elephants, human beings) as in all other animals the physiological manifestations are those that distinguish the simplest forms of living matter, irritability, assimilation, reproduction, and in this group as in all the others the special method of manifestation depends on the structure.

Vertebrates are distinguished from other animals by the possession of an internal skeleton with a spinal column. This furnishes the framework for the body and helps to preserve the form of the animal. The bones are capable of co-ordinated movement through the irritability of the attached muscles. When a muscle contracts it becomes shorter and thicker; its two ends approach and the bones to which it is attached approach. The stimulus which moves the muscle is usually carried to it by nerves which are very sensitive. They conduct a stimulus more quickly than any other form of protoplasm, and through their intervention the muscles act more quickly than they would otherwise act.

**Assimilation.**—Assimilation takes place in vertebrates as in all other animals, but the alimentary canal and its appendages are more highly developed. For food they need carbohydrates, fats, proteids, water and salts,

and these they gain very readily from the substances which they eat. The canal is definitely divided by enlargements and constrictions into the œsophagus, the stomach, the large and small intestine. Time and space for the digestion and absorption of food are afforded by the length of the intestine, which is coiled in the abdomen. The pancreas and liver are large glands connected with the canal which aid in forming digestive juices. The kidneys excrete the nitrogenous waste.

**Respiration.**—In higher forms the body cavity is divided by the diaphragm into two parts. In the upper part the lungs are situated. The lungs correspond to the gills of aquatic forms. They are composed of a thin membrane arranged to form air sacs, in which blood vessels are situated. Air from outside enters the air sacs and comes in contact with the moist membrane of the lungs; oxygen passes into the blood and from the blood into the cells of the body. Carbon dioxide passes from the cells into the blood and from the blood to the air in the lungs, thence to the outside. The entire process depends upon the law by which gases move from a place of high pressure to a place of low pressure. The air enters the lungs because the pressure is reduced there by the sudden enlargement of the chest cavity caused by the contraction of the diaphragm and the elevation of the ribs. Oxygen enters the cells because its pressure is reduced in the cells through its use in the manufacture of protoplasm.

**Reproduction.**—The reproductive organs are very prominent, especially in the breeding season. In vertebrates reproduction is sexual and depends on the union

of two dissimilar cells. In most aquatic forms, eggs and sperm are turned loose in the water. They unite and the new cell divides and differentiates until an animal like the parent is formed. In higher animals, or rather in land animals, the process is similar, except that the cells cannot be turned out in the air, where they would die, but unite in the tube which leads from the ovary to the outside. There they develop to a greater or less degree before they pass to the exterior.

**General Characteristics.**—There are no external signs of segmentation in the vertebrates, but the internal parts are arranged with special reference to the segmented vertebral column and spinal cord.

Except for localized hardening of the skin found, for example, in the scales of fish and reptiles, or in the hoofs and nails of other forms, there is no external skeleton. There is, however, an internal skeleton consisting of a skull and spinal column which supports appendages, sometimes unpaired but usually paired.

The central nervous system, consisting of a brain and spinal cord, is dorsal in position. The sense organs are well-developed, especially the eyes and the ears.

Gills are present in aquatic forms, lungs in terrestrial forms. Gill slits are present in them all, but they are lost in higher forms in adult life.

The circulatory system is closed. The heart lies ventrally in the pericardium. It is divided into an auricle and ventricle in gill-breathing forms, and contains only venous blood. When lungs are present it is further subdivided into right and left halves so that arterial is separated from venous blood.

The development of the alimentary canal depends upon the character of the food that is eaten and the length of time that is necessary for its digestion. In all forms it is a tube open at both ends to the outside, with one or more definite enlargements. It is too long to pass directly through the body and is therefore much coiled.

Reproduction is strictly sexual and the sexes are usually separate. The excretory ducts usually act as ducts for the reproductive organs.

**Classification.**—The vertebrates are divided into:

*Pisces* or *fish;* aquatic forms breathing by gills, usually covered with scales. The venous heart is divided into an auricle and a ventricle.

*Amphibia,* e.g. frogs; aquatic forms usually having true feet. The heart is divided into two auricles and a ventricle. A metamorphosis is common. Bushy, external gills are present in the young; lungs in the adult. These may persist together or they may succeed each other.

*Reptilia,* e.g. snakes, turtles; having strongly ossified skeleton and cornified skin. The heart is divided into two auricles and two incompletely separated ventricles. They have no functional gills.

*Aves* or *birds;* warm-blooded animals having wings and feathers. The four-chambered heart is completely divided into right and left halves.

*Mammals,* e.g. cows, dogs, human beings; warm-blooded animals with hairy skin, four-chambered heart, highly-developed teeth having roots. Very low forms lay eggs; others bring forth their young alive. The young are nourished by milk.

## CHAPTER XIV

## PLANTS

**Irritability.**—As plants as well as animals are composed largely of living matter, they as well as animals manifest the physiological qualities of living matter, irritability, assimilation, and reproduction, and the manifestation is governed by the same physical and chemical principles. To understand, then, the life history of any individual plant, its irritability, assimilation, and reproduction must be studied in relation to its structure, upon which the peculiar way in which they manifest themselves is dependent.

Plants are very irritable. Within the cell the protoplasm is in constant motion. In addition many of them are able to move as independent organisms. Lower plants through the activity of cilia move readily from place to place. Higher plants are usually firmly fixed, but they respond readily to external forces such as heat, light or gravity, and bend the whole or a part of the body in the direction of the acting force. Any number of illustrations might be mentioned such as the twining of the tendrils of peas, the snapping together of the valves of venus fly-trap, the turning toward the sun of heliotrope, the shrinking of a sensitive plant, and the drooping of the leaves of oxalis.

**Assimilation.**—The assimilation of plants involves the transformation of water and carbon dioxide into starch, the use of starch, oil, mineral substances in forming protoplasm, the disintegration of protoplasm, the giving off of waste in the form of water and carbon dioxide, and the passage of these products throughout the plant. If a branch bearing leaves is enclosed in an air-tight jar the water that is given off may be caught on the sides of the jar. If a branch is enclosed with a dish of lime water the carbon dioxide given off in the process of breathing will turn the lime water milky. Oxygen given off in the formation of starch may be caught by inserting a funnel over a mass of water plants exposed to the sunlight.

**Reproduction.**—Reproduction is both sexual and non-sexual, as it is in animals. In non-sexual reproduction, fission, budding, growth from cuttings take place; while in sexual reproduction two dissimilar cells unite and the new cell divides and differentiates until a new organism is formed. There is a most remarkable connection between the sexual and non-sexual methods of reproduction, not unlike the alternation of generations found in the jellyfish, where a non-sexual generation produces a sexual generation and the sexual generation in turn produces a non-sexual generation. In plants, however, this is not a more or less isolated case. It progresses steadily from low flowerless plants to the flowering forms. At first the sexual generation is prominent and the non-sexual generation very insignificant as in the liverworts. Later, by a series of gentle gradations, the non-sexual generation becomes prominent and

the sexual insignificant, as in the ferns and flowering plants.

The activity of plants as of all organisms may thus be reduced to the effort of protoplasm to manifest its inherent properties—irritability, assimilation, reproduction.

# APPENDIX

To the teacher who is quite satisfied with her own method the author does not venture to make suggestions. If she is efficient she does not need them, if she is not, she would not know how to make use of them if they were offered. To the young and enthusiastic body of women who have feelers out in all directions for anything that may be made to serve them, the author can not refrain from saying a word.

There is no profession so nerve-racking and so deadening as teaching unless the teacher has a viewpoint that keeps her interest perennially fresh. The subject-matter itself is not sufficient, for no matter how alive it may be in the beginning it will become dead after it is repeated, as sometimes happens, two or three times in one year and a single lesson four or five times in one day. There is an unfailing source of interest, however, in the minds of the pupils. Every change of class brings fresh minds to work upon and the reaction of a thought upon these minds is vitally interesting.

In the course of a month a teacher may come to know the way in which her pupils look at things so well that she can predict whether an individual will be able to answer a question and just what answer he will give. This is of infinite importance in presenting a subject to a class. A fact may not be interesting in itself, it

may not be of the least value to a child in itself, but the way in which he looks at it and the way in which he relates it to other facts is supremely important.

Facts as facts are worth very little, they may be so much dead weight. A teacher who simply imparts facts wastes her time, and what is more important, she wastes her pupils' minds. The facts are forgotten and the mind is unawakened. The great thing, the child's mental growth and development, is unaccomplished.

There has been much unprofitable discussion over the educative value of different subjects, and mathematics and the classics have warred with each other for the first place. But every subject has educative value. Every subject can be made to appeal to the reasoning power if it is properly handled, and children like to reason. They like the sensation of using their own minds, when the privilege is accorded them. They are always wondering about things and they are always asking questions if their curiosity has not been stifled by inconsiderate grown people and they have not found their asking unprofitable.

One thing that a teacher should do for a child in her care is to preserve his legitimate curiosity and foster his reasoning faculty. No subject is better fitted for this than physiology, for it is closely related to other subjects, and is full of causal relations. A good teacher who knows her subject, and a few other things, can not help correlating it with everything in the universe that has come within her ken that will help her pupils to grasp an idea or follow a chain of reasoning.

The first thing, then, is know your subject, not simply

a more seasonable time, sometimes they were unanswerable. But there was no difficulty about correlation. Every subject that could be correlated with botany was touched upon and many hazy points cleared that had been left over in other subjects. And the teacher never turned out a class which in the same time had absorbed so much botany, and whose members were so well able to make observations and draw their own conclusions.

Such a method reacts on the teacher. Her mind can not grow stagnant, it has to be alert or she will be caught fatally napping. And she learns very quickly that nothing is gained by pretense. Sooner or later "bluffing" will cost her the children's confidence and respect. If she does not know a thing it is safest to confess ignorance. If she has a sufficient mental equipment she can afford to forego the pretense of omniscience.

Since the introduction of laboratory work in the schools many teachers have been blinded by its obvious advantages and have allowed it to usurp the place of a more important phase of the work. It is introduced in so many subjects and takes so much time that, to accomplish the tasks set him, the pupil spends all of his time working in the laboratory and transcribing the results in a notebook. The result is that he gets no chance to think over what he has seen or done, and digest it in his mind. Laboratory work is of no value unless it is made a suggestive basis for mental excursions and unless the suggested thoughts are seized upon and made to crystallize.

To study a section of potato takes the average pupil

about four hours, but to understand what it suggests takes three or four weeks. Practically only two things are to be seen, many transparent globules and definitely arranged lines which enclose the globules. A young student sees these things and can make a very creditable picture of them, but if he is questioned it will be found that his idea of the meaning of his sketch is very hazy. He should not be forced to go on, then, until his difficulties have been cleared away and the suggestiveness of the section has been exhausted.

He may know, in a general way, that the potato contains starch and that cells are to be seen with the help of the compound microscope. But it is fatal to a real interpretation of what he sees if he is allowed to use these words before he is sure of their meaning, for he is apt to use them indiscriminately. It is much better for him to use some non-technical word in the beginning that simply describes what he sees. It matters very little if he calls the cell walls, lines, and the starch grains, globules, if he is able to find out for himself that the lines are the walls of a box that enclose the globules and that both lines and globules are insoluble solids. The premature use of a word or a phrase to clothe an idea that is not perfectly clear means the raising of a barrier which may entirely prevent or indefinitely delay perfect understanding. It is often wise to use a circumlocution to express an idea until one is sure of using the word without losing sight of the thought. Carelessness in the use of words results in such very absurd ideas and so much is gained in mental power by accuracy in using them that it is surprising to find

how little attention is paid to this phase of school work. A new word is often learned before the idea which it embodies is fully grasped, or the idea slips away, and the word comes to be substituted for the idea. It is then used at random, singly or associated with other words in catch phrases, without a vestige of the underlying meaning in the mind.

Such simple words as solid, liquid, gas, heat, combustion, chemical, physical, etc., are often used with so little understanding of their real meaning, that one is blinded to perfectly obvious relations. A word is supposed to be the sign of an idea, but words are often used to cover up a dearth of ideas. Even the wisest of us is apt to fall into this shiftless habit, and it is no mean offense, for it is a sign that one is falling into a lazy habit of mind. It means finally the loss of mental alertness and the joy of using one's own mind, which, after all, is one of the greatest joys one can have.

Even at the risk of being too diagrammatic it is sometimes worth while to put the ideas that very simple words stand for in a form which can be readily visualized. By visualizing the meaning of the long familiar word heat, for example, it may be made to assume a new force and to bring ideas which have been hazy or unconnected into a logical and definite relation. Heat transference, expansion, evaporation, should not be isolated ideas, but very definite corollaries of the fact that matter is made of molecules which move and have spaces between them. A pupil may understand such a series of ideas and yet not be able to apply them to the explanation of even simple phenomena.

With a little help, however, in a few specific instances he will gain the power of making the application for himself, and one of the great aims of school teaching will be realized. A pupil who can use what he knows effectively has really made progress educationally, but if he can do nothing but remember what someone else has told him, he is outside the field of mental interest. This method may sometimes seem discouragingly slow, but time is never lost if it is used so that in the end the pupil is ready to think and ready to find thinking interesting.

# REVIEW QUESTIONS

These questions are not intended for consecutive classroom use. Neither is it intended that the pupil shall turn to any specific page for an answer. When he has completed the book he will find that he will be able in most cases to answer the questions without reference to the text and that his effort will be an easy method of review.

1. Explain evaporation without using the word heat.

2. What has evaporation to do with human physiology?

3. In what way is the economical principle of division of labor exemplified in the development of animals?

4. Why (physiologically) does a dog pant?

5. How is the same result accomplished in human beings?

6. Does anything similar happen in frogs? Explain.

7. Should toads be killed or preserved? Earthworms? Caterpillars?

8. Is it necessary to chew soft foods?

9. Trace the digestion and absorption of a drop of milk.

10. Why can we not commit suicide by holding the breath?

11. Are the blood corpuscles living or dead? Are the white and red corpuscles composed of the same material?

12. Are potatoes fattening? Explain.

13. Mention a many-celled animal that does not have a circulatory system and explain what compensates for its lack.

14. Does the blood flow faster in the capillaries or in the arteries? Explain.

15. What is the physiological cause of blushing?

16. When an earthworm is touched it crawls away, when an anemone is touched it merely jerks back close to its support. Explain physiologically and mechanically.

17. To what physiological factor is the sensation of cold due?

18. Why is it considered unsportsman-like to "hit below the belt"?

19. Why should plants not be kept in the bedroom at night? Is the same thing true in the daytime? Explain.

20. Muscular exercise is a source of heat. Why can not fever be produced by muscular exercise?

21. Why does fanning a wet object help to dry it?

22. How does it happen that too much exercise and too little exercise affect the body in the same way?

23. What change takes place in a man's body as he ascends in a balloon?

24. Why does watering the lawn make one feel cooler in summer?

25. Is there any physiological process in man comparable to regeneration in starfish? Think carefully.

26. How does it happen that warm-blooded animals have a constant temperature?

27. Give an argument against the idea that food is in the body as soon as it is swallowed.

28. Is the curdling of milk comparable to any physiological process?

29. Describe the interdependence of plants and animals.

30. Why does blood collect in the finger when a band is tied around it?

31. Why does the foot of the crossed knee jerk if the knee is struck?

32. What causes fever?

33. Show how the sexual reproduction of Vorticella is a connecting link between the conjugation of a simple form like the paramecium and the fertilization of more highly developed forms like the sea urchin.

34. Show the relation between chemical action and human physiology by reference to the waste and repair of the body.

35. How is heat produced in the bodies of plants and animals?

36. Trace the development of the digestive system, using for examples the hydroid, jellyfish, starfish, earthworm, clam.

37. Show how the characteristic movements of animals are dependent on their structure, using for examples the ameba, jellyfish, lobster, fly.

38. Show the connection between muscular exercise and other functions of the body, particularly circulation and respiration.

39. Explain the position of the diaphragm when relaxed.

40. Is there any relation between the sap in a cell from a flower hair and the starch in the potato cell?

41. Starch grains increase in size and also stream across the field of a microscope. How do these processes differ from the growth and motion of an ameba?

42. Mention three processes in the human body dependent on the physical principle of equilibrium (balance of activity).

43. In what way does the weight of the air affect the physiology of organisms?

44. In considering the differences and the similarities of lower and higher animals, which seem to you the stronger factor in the development of the world as it is to-day?

45. Is your respect for lower animals increased, or is your respect for man decreased by a consideration of the similarity of their bodily functions?

46. Is your respect for a higher power increased or decreased by a consideration of the laws that govern the physiology of organisms?

To compare two things is to point out both resemblances and differences. By bringing the general characteristics of two different things into juxtaposition, the characteristics of both are fixed in the mind. Compare

1. Living matter with non-living matter.
2. Plants with animals.
3. One-celled animals with many-celled animals.
4. Lymph with blood.
5. Arterial blood with venous blood.
6. The constitution of milk with the constitution of blood.
7. Fission with budding.
8. Conjugation with fertilization.
9. Sexual reproduction with non-sexual reproduction.
10. The structure of a sea-anemone with the structure of coral.
11. The structure of a sea-anemone with the structure of a hydroid.
12. The structure of an earthworm with the structure of a lobster.
13. The symmetry of an earthworm with the symmetry of a starfish.
14. The making of starch with breathing.

15. Breathing by gills with breathing by lungs.
16. The action of nerves with the action of muscles.
17. The anal spot with the contractile vacuole.
18. Scientific *law* with *law* of the land.
19. The arm of a human being with the leg of a lobster.

# INDEX

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